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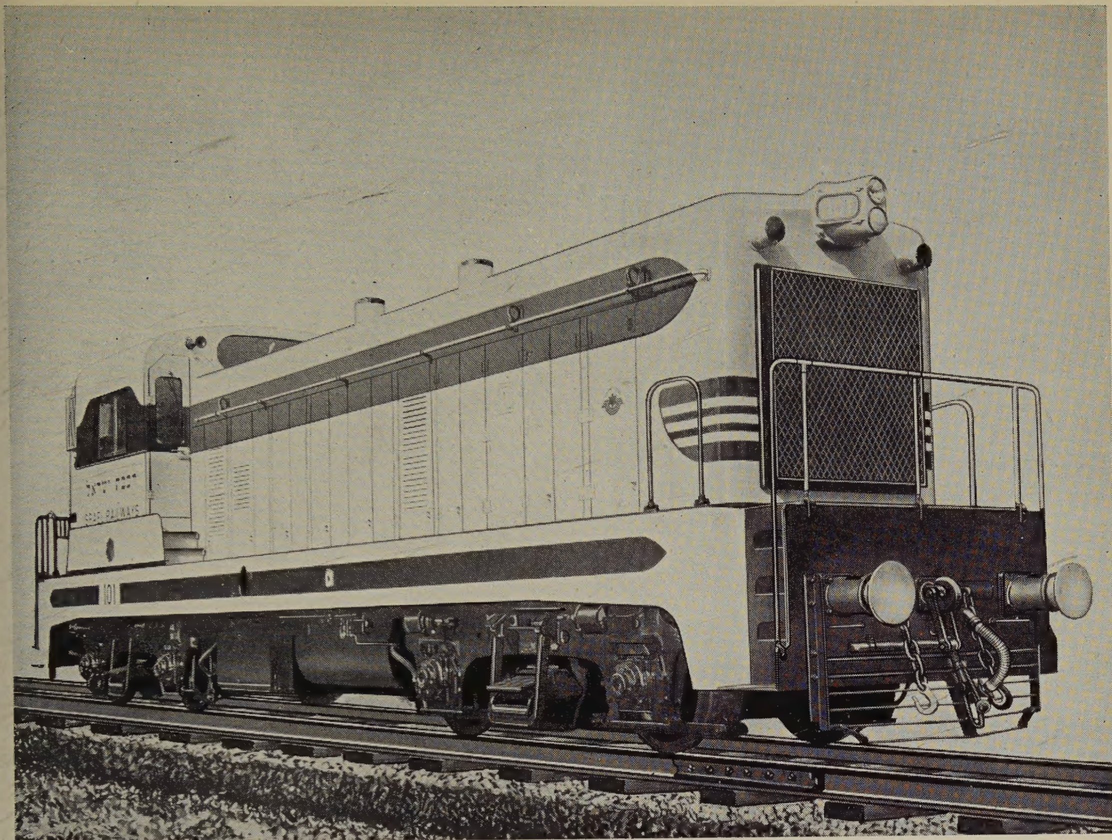

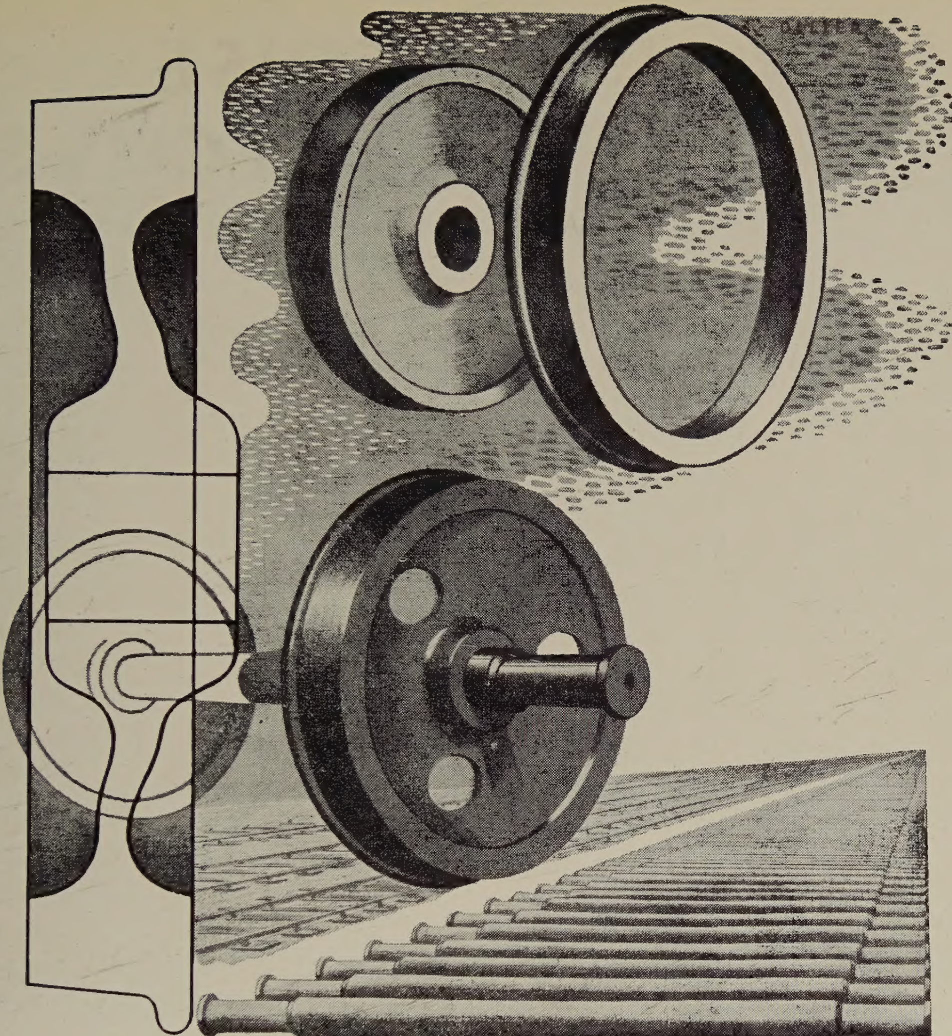

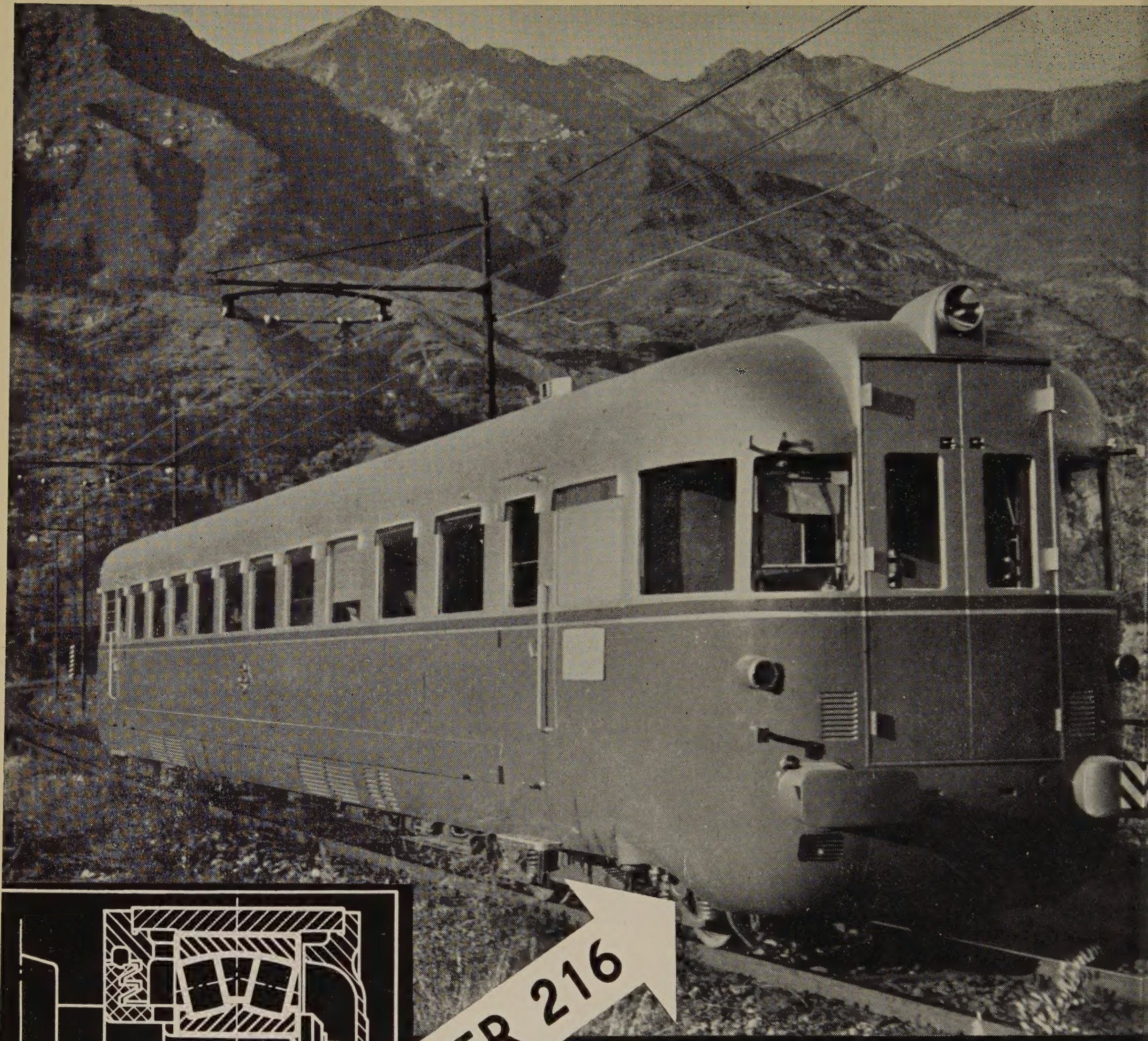

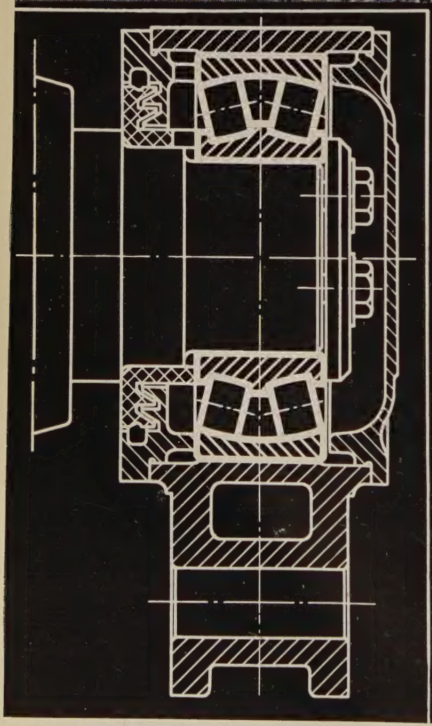

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BULLETIN
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(ENGLISH EDITION)

[625 .14 (01 & 625 .2 (01]

The geometrical conditions of the contact between rail and wheel.

The apparent contour of the tyre and the manner in which it negotiates the curves in the track,

by M. Bouteloup,

Hon. Chief Engineer of the French National Railways.

(Revue Générale des Chemins de fer, April 1952).

This memorandum reverts to a problem touched on by the author in the Revue Générale *of October 1947, and in the review* L'Industrie des Voies Ferrées et des Transports Automobiles *of October and December 1948. This problem is as follows :*

The geometrical relationships in the contact between rail and wheel have hitherto been insufficiently known on account of the lack of methods available by means of which the action taking place could be reliably reproduced and studied in spite of the numerous researches undertaken with this object in view.

Under what conditions do we get a single contact between wheel and rail? Under what conditions and at what point does a second contact come into operation, causing friction and chamfering of the rail; wear of the wheel flange which results in a cutting edge enabling the wheel to mount the rail and producing the derailment? This problem which simultaneously engages the attention of the designs drawing office, the office dealing with tyre maintenance and the section studying the occurrence of accidents, will the author hopes be met in the first instance by a very simple explanation. This is based entirely on the elementary geometric interpretation of a slightly complex analytical problem of solid geometry; from which we get arrangements that are both quickly and easily manipulated.

M. BOUTELOUP now submits a continuation, a truly unanswerable confirmation of his first argument, as simple as the first one, and which appears to provide effectively the means of dealing rapidly and reliably with the problems concerning tyre sections, dimensions of the flangeways of the track, clearance between wheel-flanges and rails : in short, the plotting of the tyres at the inside edges of the track rails (and at the outside edges of the guard rails), whether it is a question of the track rails or of the safety appliances.

The author thinks that these researches will permit of a clear view being easily obtained of a situation which has hitherto been obscure, and that the contemplated methods of examination will enable reliable tests to be made on difficult lines without risks, and able to reduce wear of materials and to improve the running of trains.

CAPITULATION OF RESULTS ALREADY SECURED.
SOME COMPLEMENTARY FACTS AND NEW PROPERTIES.

We are already aware that when an axle approaches the track more or less obliquely the tyres meet with a reduced amount of play between the rails, in other words they are working to a reduced gauge.

The limit of this gauge is geometrically perfectly definite : it is a *modified curve derived from the section of the rail,* which can be traced by means of a very simple geometrical construction; moreover we have also given it the name of *meridian,* because it is the meridian of the surface of revolution which would enclose in space the rail revolving about the centre line of the axle.

For construction (fig. 1) we start with the point A in the section of the rail, and tracing the normal AN, we place the subnormal height PN making it equal to Ri^2 (R radius of the wheel, i its angle of attack, so that Ri^2 is a dimension in length) and,

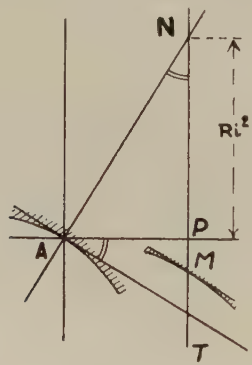


Fig. 1.

on the height PT sub-tangent, the point M at the centre of PT is the point of the transformed curve « Ri^2 » which corresponds to point A. Its tangent runs parallel to the tangent at A.

A distinct transformed curve corresponds to every value of the variable Ri^2. All these curves are falling parabolas (fig. 2). They are conveniently designated by the value of Ri^2 which characterizes them and which is given in millimetres : 0 to 2 mm for the main networks; 0 to 3 mm for local branch lines; 0 to 6 mm for tramlines with curves of about 15 m radius [1].

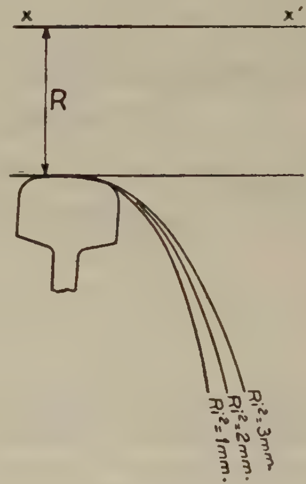


Fig. 2.

It is easy to verify that all the modifications of any one rail are derived, one from the other (a property which we have hitherto not yet pointed out).

And with respect to the modification Ri^2, the modification Rj^2 behaves like its modification $(Rj^2 - Ri^2)$ deduced from it by using as variable the difference of their variables $(Rj^2 - Ri^2)$.

The fact that the obliquity of the section of the tyre keeps it away from the section of the rail (at all events in the plane of

(1) If a name was needed for this set of curves, we would propose to call them « r-i-bis curves » or abbreviated « ribis », a name recalling their method of construction which has the advantage of being pronounced in the same manner in all languages. One could say a ribis of the rail of 46 kg, the ribis 2 mm. We will see further that the apparent contour of the tyre is a ribis of the tyre.

the figure which is the vertical view of the axis of the axle) is equivalent to *an apparent bending of the rail*, an expression which will be convenient to make use of and to state its value in figures.

For exactly similar reasons, it is worth while to take into account *modifications of the guard rail*, an *apparent flexure of the guard rail* (fig. 3); and everything that takes place is as if the *flangeways had been*

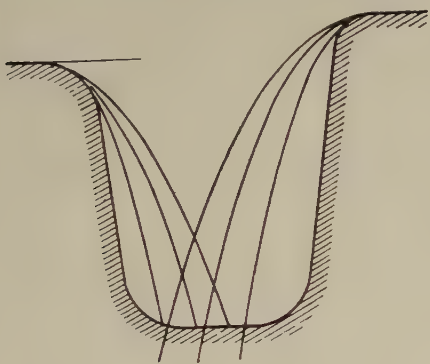


Fig. 3.

reduced by the whole value of the flexures added together. As regards the tramways where the very narrow flangeways of the Broca type rails require it, a very special tyre section cut away at the inside as also at the outside (fig. 4) is provided.

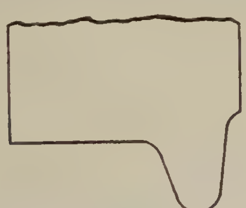


Fig. 4.

Added to these phenomena there is a further feature : owing to the obliquity of the axle, the two wheels approach each other at the central plan of the track by an amount $1/2\ Ei^2$, and this action produces an *apparent shortening of the axle*.

This apparent shortening is achieved by an apparent reduction of the apparent bending of the rail and replaces at the axle a little of the play in the track;

but it adds to the apparent bending of the guard rail and consequently diminishes the play of the axle with respect to the guard rails which are framed between the two wheels.

This fact may itself call for an increase in the gauge of the track *on curves*, as a function of the rolling stock to be run thereon; this however leads to a very limited addition to the gauge.

As regards *tramways* and generally to lines having flangeways (e. g. : Broca rails), the apparent shortening of the axle increases the difficulties met with at the guard rails : one is led to a *reduction of the gauge width on a Broca curve*, and this can only be got over by allowing a diminution of the inside as well as the outside play conceded to the axle in the track.

These are the notions already acquired from earlier studies which we have thought good to capitulate and to add a little to them at the present enquiry.

NEW RESEARCH ON THE TYRE PROBLEM.

PART PLAYED BY THE APPARENT CONTOUR.

In the foregoing research, we have in a manner of speaking, considered the tyre from the front, placed the rail in different positions more or less oblique to the tyre, and have decided at which point and under which angle of inclination the contacts are produced.

One may get the idea to view the rail in turn from the front, to place it in some way at right angles to the view and to ascertain the angle at which the tyre presents itself to the view : and then whether a single contact is shown between the rail and the tyre or alternatively several contacts, a projected view on these lines will show the entire rail in a vertical section, *the tyre will appear in the form of its*

apparent contour, and the contacts between the rail and the tyre will appear as contacts between the section of the rail and the apparent contour of the tyre : in this way, it will be seen at what level and under what angle they will be produced. The problem to be solved is now restricted to *determining the apparent contour of the tyre when viewed from a certain angle.* It will be observed that this apparent contour might in other words be termed, the gauge or the space occupied by the tyre placed obliquely and moving in the same sense as the track.

In order to make the foregoing statements clear, we refer to Appendix I for the considerations, very simple moreover, of the analysis and geometry which lead to the final result. Their procedure is strangely similar to that which served for the study of the rail and it led to an identical construction. We give here the essential results.

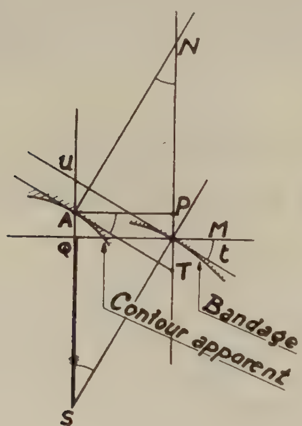


Fig. 5.

Bandage = tyre. — Contour apparent = apparent contour.

1° *Construction of the apparent contour of the tyre.*

The construction of the apparent contour is obtained by the three following operations (fig. 5) :

— at each point M of the tyre the tangent is drawn, the normal and a horizontal line, and a subnormal vertical S Q = Ri^2;

— on the vertical S Q the point A, centre of the sub-tangent of height Q U is the point of the apparent contour corresponding to the point M;

— the tangent at A to the apparent contour is parallel to the tangent to the section of tyre, having an inclination t to the horizontal.

It will be observed that this construction is exactly the same as that we referred to earlier for the construction of the meridian enclosure of the rail revolving about the axle.

It will be observed that it is valid whatever be the shape or degree of deformation of the tyre.

2° *The section of the tyre and its apparent contour are reciprocal curves.*

Figure 5 in fact at once shows, that these points A and M are reciprocals.

3° *All the apparent contours corresponding to different values of* Ri^2 *are transformations of one to the other.*

Two transformations of different variables are derivable one from the other by taking as the subnormal height or variable Ri^2 the difference between their variables.

(See *Appendix,* second property, p. 721.)

4° *Different forms of apparent contour.*

Although we obtain by identical construction the transformation of the tyre, which is its apparent contour, and the transformation of the rail, meridian of its enclosure, there is an essential difference between them : this is that the rail is a convex solid and that we take the external transformation of its cross section, which latter always has a radius of curvature greater than that of the rail itself. The throat of the tyre has on the other hand a concave cross section and we take the internal transformation, which always has a radius of curvature less than that of the

tyre; hence it happens quite naturally that, with sufficiently high inclination values t the radius of curvature cancels out and the apparent contour shows a *point of retrogression.*

This is a case well known to all students of special mathematics who have made a working diagram of the apparent contour of the torus (fig. 6 *a*) and one can understand the phenomenon by observing the neck of a bottle slightly square in the form (fig. 6 *b*).

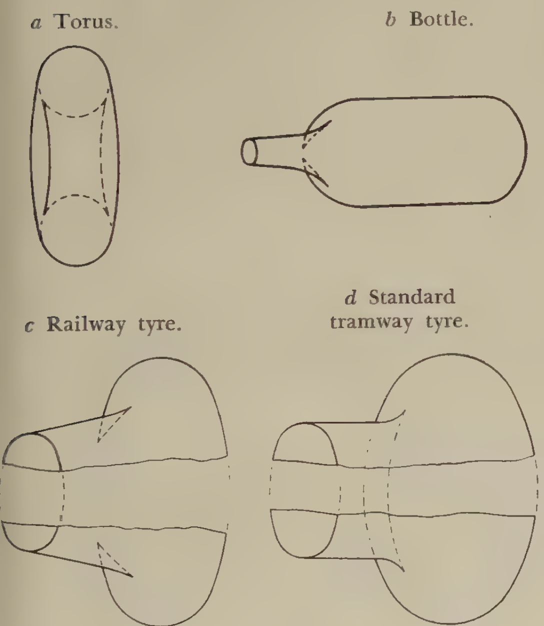


Fig. 6.

In the case of the tyre, there exists between the radius of curvature of the apparent or transformed contour A (enclosed curve) and the radius of curvature of the tyre M (enveloping curve) the relation

$$r_a = r_m - \frac{Ri^2}{\cos^3 t}$$

t being the angle which is made by the tangent to the section of the rail with the horizontal.

(For the demonstration we refer to our article of 1947, p. 350.) (*)

This curvature cancels out and the apparent contour consequently presents a point of retrogression if on the tyre there is a sufficiently marked point of inclination and if the value of cos t is small enough to make $\dfrac{Ri^2}{\cos^3 t}$ greater than r_m, radius of the throat of the tyre.

For instance with the S. N. C. F. standardized tyre where the radius of throat of tyre is $r_m = 15$ mm and where $t = 70°$; $\cos t = 0.342$; $\cos^3 t = 0.041$, there is a retrogression of the apparent contour for all obliquities of the axle i such that we have :

$$\frac{Ri^2}{\cos^3 t} = 15 \text{ or } Ri^2 = 15 \times 0.041 = 0.615 \text{ mm.}$$

This case occurs frequently. For a wheel of dia. 2 R = 1 m (or 2 R = 2 m) there is retrogression in the apparent contour as soon as the angle of incidence i reaches 35 $^0/_{00}$ (or for a wheel of 2 m : 25 $^0/_{00}$). The apparent contour of the tyre then shows an ascending limb; this limb ceases to rise and descends again when it reaches the rectilinear part or at the bend which precedes the lower rounding off of the flange (1) (see fig. 6 *c*).

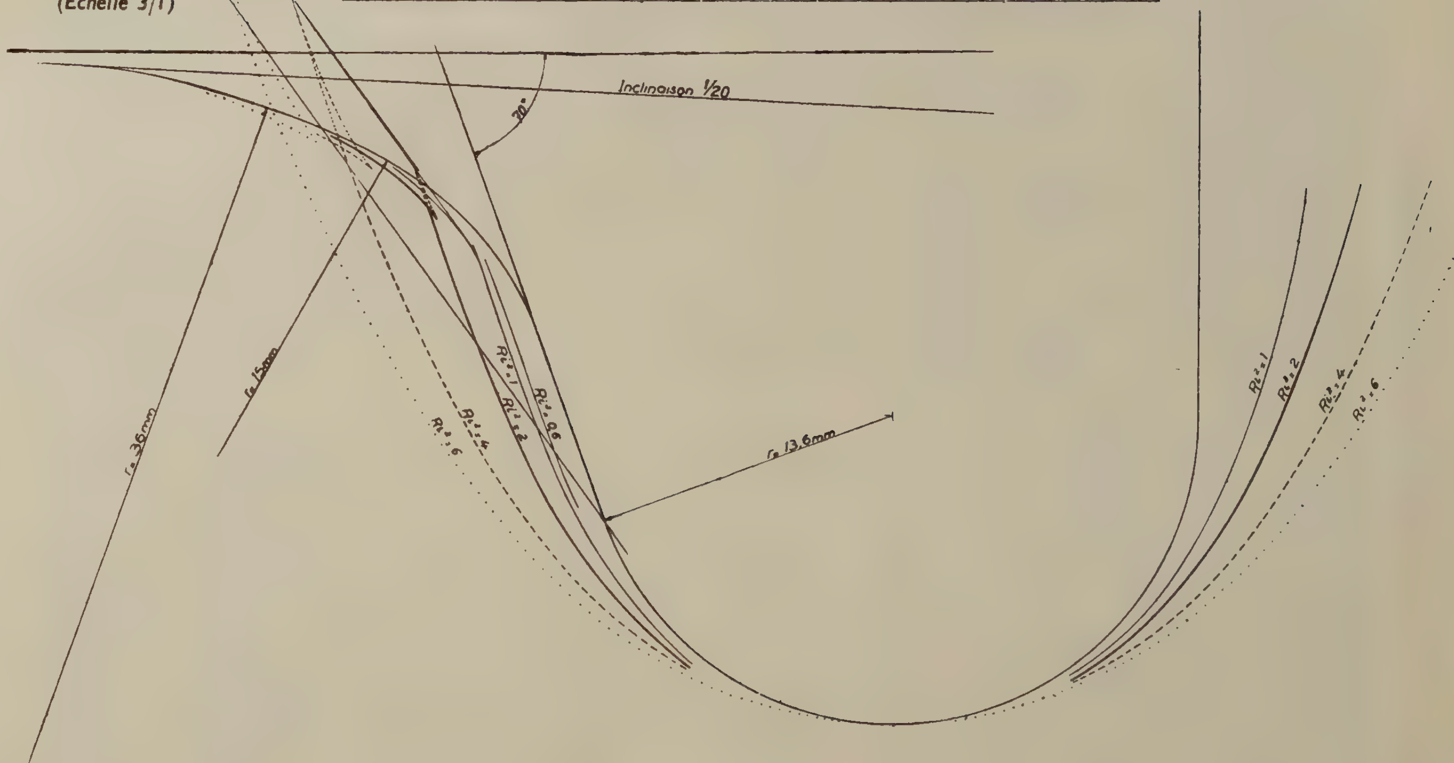
(*) See also *Congress Bulletin* of July 1949, pp. 527/528.

(1) Here we must make a correction of our statement in the *Revue Générale* of October 1947, p. 342 and fig. 3, where the reality of this rising limb had not been apparent to us.

It should be added that if the tangent of inflection, in the cross section of the tyre, is very near the vertical and makes with the vertical a smaller angle than the angle of incidence of the rail at the wheel, the ascending limb does not descend again and is continued to the upper part of the wheel : the apparent contour of the throat and the external contour of the flange thus form two curves of parallel form which do not meet : this case applies to the standard tramway tyre, where the tangent of inflexion is vertical (see fig. 6 *d*).

Planche I
(Echelle 3/1)

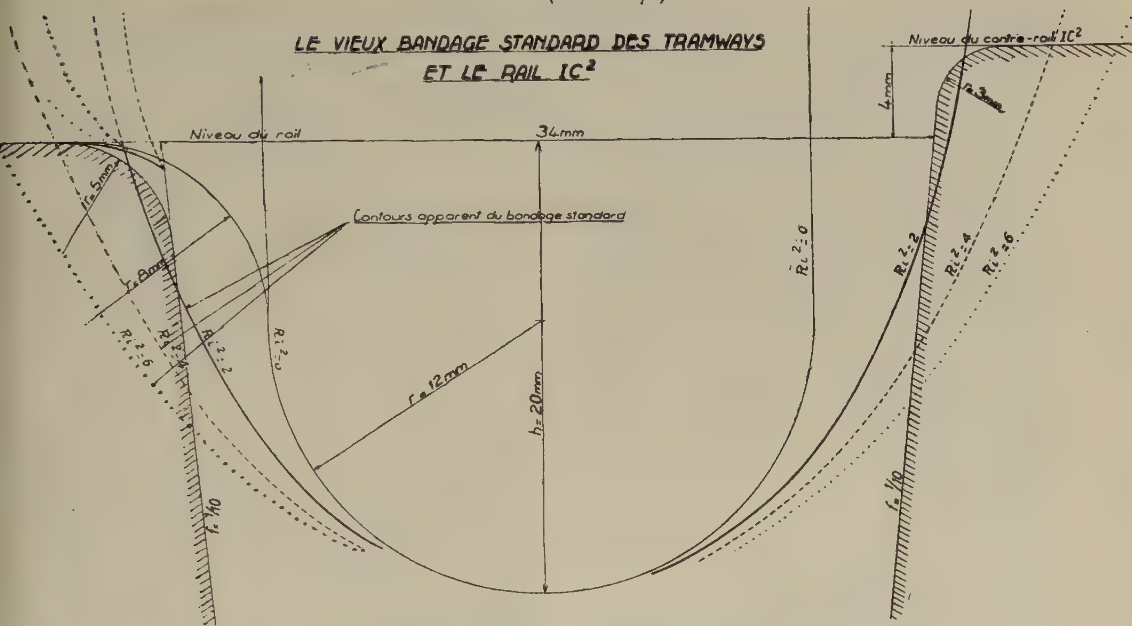
LE BANDAGE UNIFIE DES GRANDES LIGNES ET SES CONTOURS APPARENTS



Explanation of French terms:

Planche I (échelle 3/1) = plate I (scale 3/1). — Le bandage unifié des grandes lignes et ses contours apparents = the standardized tyre of main lines and its apparent contours.

Planche II *(Echelle 3/1)*



Explanation of French terms:

Planche II (échelle 3/1) = plate II (scale 3/1). — Le vieux bandage standard des tramways et le rail I C^2 = the old tramway standardized tyre and the rail I C^2. — Niveau du contre-rail I C^2 = guard-rail level I C^2. — Niveau du rail = rail level. — Contours apparent du bandage standard = apparent contours ot standardized tyre.

Plates I and II give us the shape of the apparent contour of the standardized tyres for the different values Ri^2 = 6 mm, 4 mm, 2 mm and 0.6 mm. The value Ri^2 = 6 mm slightly exceeds the highest value attained by the longest trams without bogies in the tightest curves in the towns (Ri^2 = 4.2 to 5.4 mm for the old motor driven types L in the city of Paris). As we have said above, the values fall below 3 mm for narrow gauge railways, and 2 to 0.5 mm occur most frequently for lines in large networks. It is well to remember here that the angle of incidence i is the sum of several components of which the principal on a curve, is the angle between the longitudinal axis of the vehicle, forming the chord, with the tangents to the curve at the two ends of its fixed wheelbase; this angle having the value $\frac{L}{2C}$, L being the fixed wheelbase and C the radius of curvature; for instance, a large vehicle with parallel axles and 9 m wheelbase, on a curve of 250 m radius, gives an angle of incidence of $\frac{9}{500}$ or 18 $^0/_{00}$. To this is added the play of the axle in the track, which allows of the necessary diagonal negotiation of the curve by the vehicle and all the structural play, wear and even the elasticity of the car can be utilised in its nosing action.

Whether the cross sections of the tyres have a more or less flat tangent of inflexion, or whether they have a more or less small radius of throat, it is observed that the apparent contour preserves the same general character : its horizontal limb only flattens or rises by a small amount.

5° *Points of contact between the rail and the tyre. — Their position in space.*

Every contact between rail and tyre is directed towards the rail, like a contact

between the section of the rail and the apparent contour of the tyre. It would therefore be possible to find the possible contacts by sliding over the different apparent contours of the tyre a section of the rail (e. g. a section on tracing paper) suitably located. We recommend working with large scale drawings, to get good results. A scale of 10 to 1 is the best and it dispenses with any calculations. We used a scale of 3/1 in the plates, only to keep down the size of the printed sheets.

Contact being imagined to take place at A (fig. 7), the point where it actually takes place and which corresponds to point M on the tyre is projected at A but does not appear exactly in the vertical plane passing

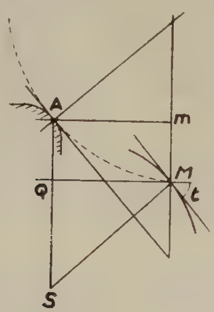


Fig. 7.

through the centre line of the axle and including the section M. It will be seen in Appendix II that the said point either lags or leads by an amount $\frac{MQ}{i}$, i being the angle of contact.

Since moreover, $MQ = QS \ \mathrm{tg}\ t = Ri^2 \ \mathrm{tg}\ t$, it will be seen that the contact will take place in advance of or behind by a *distance* $\frac{(Ri^2)}{i}$ tg t or Ri tg t proportionately to tg t (Ri being constant for the whole section), i. e. proportional to the inclination of the profile of the rail at this point.

Thus it will be seen that in the event of a double contact, the first contact will take place at a negligible distance from the plan of the figure; but that the second contact, on the fillet of the rail may on the other hand be notably distant. In the case of the standard tyre for $t = 70^\circ$ and tg $t = 2.747$, it will take place at a distance of 2.747 Ri. For example for a wheel of 1 metre ($R = 0.50$ m) and if $i = 50\ ^0/_{00}$, this distance is about 7 cm, since :

$2.747 \times 0.5 \times 0.050 = 0.0687$ m, say about 7 cm. With a less receding flange and a more vertical tangent, the contact would be still more distant.

6° *Apparent contour of the internal surface of the tyre.*

All that has been said of the external surface of the tyre is applicable to the internal surface; it presents an apparent contour which is obtained by the same geometric construction and which it will be interesting to consider for the contacts with the guard rail and for the free passage of the flange in the flangeways of the track, more particularly for the passage in the Broca rails when we are dealing with tramways (fig. 8).

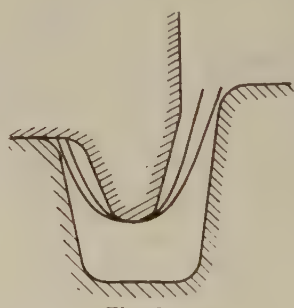


Fig. 8.

The different shapes of apparent contour which the internal face of the tyre may present are analogous to those presented by the external face. However, if that face is not hollowed out they are not concave like the tyres of tramways of which we have referred to earlier, they do not present a straight line surface, nor a tangent of curvature, nor a point of retro-

gression; hence they have a rounder appearance (see plate II).

7° *Apparent swelling of the flange. — Apparent shortening of the axle. — Passage through the track and through the flangeways.*

In general and at whatever level the measurement is made, the apparent contour has the appearance of *a swelling of the wheel flange.*

But in this case the problem has an altogether different importance according to whether it is a question of a railway or a tramway.

The tramways for which the consequences are the most serious, are essentially characterized by tracks having alignments and curves of very small radius : 20 m, 18 m and in many cases only 15 m. Practically speaking the only cars running are carried on two axles or on bogies having two axles. The wheelbases of these cars are restricted to 2.5 m or 3 m, in exceptional cases 3.60 m, but these values small though they are, reach to a fifth of the curves they have to run over; against this, the wheels are fairly small and barely exceed 830 mm; so that all in all the value of Ri^2 often reaches 4 and 5 mm, and may approach 6 mm. Moreover the track is made up of tram rails of which the grooves are limited to 41 mm on curves by decree of the 7th. July 1910 and, in fact, to 34 mm by the section of the rail I C^2 which is the international standard for curved rails.

The railways, on the other hand, have curves of large radius, which normally hardly drop below 250 m or 300 m on secondary lines, 150 m on curves and marshalling yards, if necessary 75 m for entries to works and 50 m on local lines. On the other hand, rigid wheelbases are long; they reach 9 m for certain coaches, 9.80 m for certain railcars with parallel axles, wheel diameters scarcely exceeding 1 050 mm. As regards locomotives, these have larger wheels, reaching and exceeding 2 m, but having rigid wheelbases of lesser dimensions (we have found none exceeding 6.15 m) but we must take into account coupled axles for taking curves readily. In brief, the values Ri^2, which have to be taken into account, are as follows :

for locomotives with wheelbases of 6.15 m, Ri^2 may reach 1;

for long coaches or railcars with two parallel axles, 1.8;

for short bogies, 3.5.

On metre gauge (railways) we find : curves of 100 m radius, 50 m in certain special conditions;

locomotives with wheels 1.40 m and 1.80 m wheelbase;

cars with wheels 850 mm and 3 m wheelbase;

in which, generally speaking, Ri^2 does not exceed 3.

On a 60 cm gauge, Ri^2 will not exceed 2.5.

7. a. *Case of tramways with grooved rails.*

2 axle trucks only.

As will be seen, it is only a question of two axle trucks (cars or bogies).

We have to consider 3 problems :

the entry of the wheel into the flangeway of the rail;

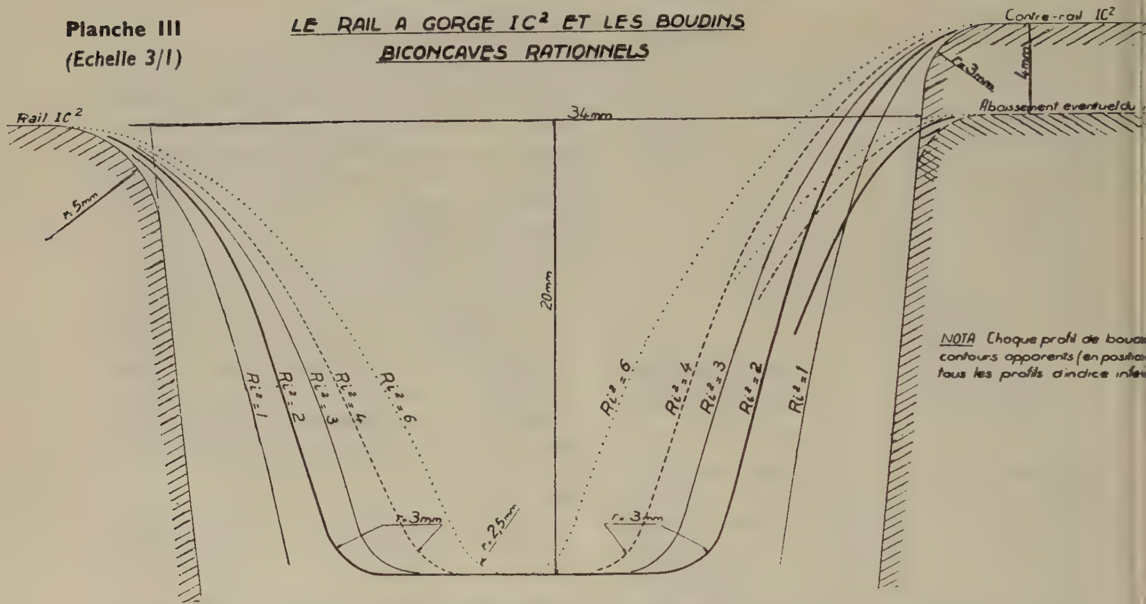
the entry of the axle carried in between the rails;

the entry of the axle carried outside the guard rails.

We shall not consider that we have to deal with the standard wheel flange of 1920, which we think has absolutely lapsed, unable as it is to run on all the usual rail patterns without serious wear and which we believe has been abandoned by all the tramways.

We shall examine this problem by means of an example, and we will imagine that we are dealing with tyres made with the internal and external cross section $Ri^2 = 4$ of Plate III. The reason why will become clear in what follows. We shall imagine that our vehicle has to run over a curve of I C^2 rails for which it adopts the characteristic $Ri^2 = 6$. Let us see what will happen.

Planche III
(Echelle 3/1)



Explanation of French terms:

Planche III (échelle 3/1) = plate III (scale 3/1). — Le rail à gorge I C² et les boudins biconcaves rationnels = rail with groove I C² and the biconcave rational wheel flanges. — Contre-rail I C² = guard rail I C². — Abaissement éventuel du contre-rail = possible lowering of guard rail. — *Nota.* Chaque profil de boudin a pour contours apparents (en position oblique) tous les profils d'indice inférieur = *Nota.* Each wheel flange profile has as apparent contours (in oblique position) all the lower sections.

7a. 1° — Entry of the wheel into the flangeway (or groove).

The simplest mode of investigation is to consider the swelling of the rail; it will lead to the section of rail according to the curve $Ri^2 = 6$; the tyre which we have chosen ($Ri^2 = 4$) encroaches by 2.2 mm at its lowest part; it will cause the wheel to move back by 2.2 towards the guard rail. But as on the other hand it recoils off the guard rail as far as the section $Ri^2 = 6$, i. e. by about 3.1 mm, it should therefore be reduced by (2.2 + 3.1) = 5.3 mm and ultimately brought to the section $Ri^2 = 6$.

Due to this, the only section of the tyre which is able to run in the groove with this obliquity is the section $Ri^2 = 6$.

It will thus be seen that a wheel of radius R, intended to enter a track groove with an obliquity of i may not have a flange thicker than that covered between the transformation Ri^2 of the sides of the groove. This condition severely reduces the thickness of the wheel flange and we proceed to consider this application [1].

[1] If one has made the calculations or drawings for the flange standardized in 1920, with its thickness of 24 mm between two vertical tangents, it would be obvious, even if the obliquity of the axle were limited to 10 % and for $Ri^2 = 4$, as would be conditional in the following paragraph, the requirements would be :

— for entry of the wheel, a groove of 41 mm;

— for the axle to pass between the rails, a gauge clearance = nil;

— for the axle to pass clear of the guard rails, a negative clearance of 14 to 15 mm, hence a groove of $34 + \frac{15}{2} = 41.5$ mm, i.e. this flange would be impossible with the rail I C² and only just possible with the biggest of the standardized Broca rails, the UVF.L with a 41 mm groove and moreover because its guard rail is not superelevated.

Which values of Ri^2 can be seriously considered ?

The condition, which has just been stated, is very severe; with values of Ri^2 approaching 6 mm only a very reduced thickness of flange is left. But the value of the obliquity *i*, which has been suggested is that which can be used by the wheel in the track by utilising all the freedoms which we have imagined to be possible. Now then, only one condition of orientation is imposed on the axle : it is that which is due to the position of the vehicle as a chord in the arc of its movement, i. e. the obliquity $\frac{L}{2C}$, L being its wheel base and C the radius of the curve; the other features which permit obliquity — play in the track, in the bearings, in the axle-boxes and in the hornplates do not impose any difficulties : there may be some friction, they do not make movement impossible unless seizing takes place, but this does not appear to be likely.

We have pointed out that in the tramways the wheelbases sometimes reach 1/5th. of the radius of the curves. Obliquity can therefore reach the value $i = \frac{0.2\,C}{2\,C} = \frac{1}{10}$, so that $i^2 = \frac{1}{100}$ and the minimum absolute permissible for Ri^2, would be $\frac{R}{100}$, i.e. 4 to 4.5 mm.

The result is that a flange which according to Plate III, might have at 10 mm in the rolling plane a thickness of about 16 mm. It should be understood that all cars having a lesser wheelbase or smaller wheels, or running over curves of larger radius can use thicker flanges. Cars of a wheelbase of 2.80 m, with wheels of 0.66 m (R = 330 mm) on curves of 18 m would have an obliquity of only $\frac{L}{2\,C} = 0.078$, value of $Ri^2 = 2$ would permit of flanges of 22 mm.

It would therefore be illogical to try to standardize this section among all the systems and even among all the vehicles of a given system : there are curves and vehicles which impose on the tyres a more or less reduced thickness of flange, and it would not be rational to inflict such reduction on all the vehicles where it is unnecessary. All that we can say is that it would not be illogical to standardize a rough forged section corresponding to $Ri^2 = 2$ or 3 (supposing the $I\,C^2$ rail to be in general use). Each system would use these rough tyre sections for turning up Ri^2 sections to suit their vehicles and their curves.

7a. 2° — Guiding of the axle at the interior of the rails.

Here again it is Plate III and the apparent swelling of the rail that gives us the conditions for guiding the axle. The rail being apparently swollen to show a section of the tyre $Ri^2 = 6$, must, in relation to the cross section of the tyre ($Ri^2 = 4$), be pushed back by 2.2 mm : the track will require a gauge increase of 2.2 mm × 2, i.e. 4.4. mm.

If the tyres had a cross section $Ri^2 = 6$, the track would not have required any increase in the gauge clearance.

If the tyres had had any section, the remaining play in the track or the increased gauge clearance to be given, would have been measured by the whole difference between the external clearance of the said tyres and the clearance between the transformations of the rails corresponding to the value of Ri^2 attained by the axle. In order to study this, it is more practical to place a tracing representing the tyre upon the plate of the transformations of the rail obtained once for all, than to draw the transformations for each tyre that calls for consideration and to slide over these the tracing of the rail section.

This first effect of apparent swelling of the tyre or of the rail has to be combined algebraically with the *apparent shortening of the axle,* due to the fact that the obliquity of the axle in the track approaches

the two wheels from the median plane of a value which we shall call $\frac{a}{2}$ the total shortening a having the value $a = \frac{1}{2}$ Ei^2 (E = internal spacing of the flanges, which is of the order of 1 420 mm for the standard track and 990 mm in the metre gauge).

If we note that the principal part of the obliquity i is due to the position of the vehicle on the chord in an arc of the curve and has the value $\frac{L}{2\,C}$, it will be seen that the apparent shortening of the axle is $a = \frac{E\,L^2}{8\,C^2}$. It can reach :

on the standard track, for the tramways, 7 mm on the tightest curves;

on the 1 m track, 5 mm.

7a. 3° — Guiding of the axle at the exterior of the guard rails.

Plate III shows that the apparent swelling of the guard rail takes it up to the section $Ri^2 = 6$, or more exactly stated, that the tyre tends to displace the guard rail towards the centre of the track by the whole length of the two cross sections, i.e. by 3.1 mm : the track requiring a reduced width of (3.1 mm × 2) = 6.2 mm.

Altogether, it is seen that each groove is too narrow by 2.2 + 3.1 = 5.3 mm.

If the tyre had been rolled to suit $Ri^2 = 6$, the track would not have called for any reduction in width.

If the tyres had had any cross section, the play remaining between axle and guard rails or the *reduced width* to be allowed would have been measured by the whole difference between the interior width of the tyres, and the transformations of the guard rails corresponding to the value Ri^2 reached by the axle. Owing to the fact that in the section I C^2 the guard rail is placed at a higher level than the rail, its transformations are set more widely apart, and the requirements due to reduced width of gauge are more severe than those due to increased width of gauge.

This is all the more so since this first effect of apparent swelling of the tyre or of the guard rails must be taken in conjunction with the *apparent shortening of the axle* which we referred to above and which, as was seen, could reach 5 to 7 mm according to circumstances.

It will be seen that in the Broca tracks, and subject to the more or less lucky choice of the exterior and interior sections of the tyre, the longest cars claim a certain reduction in gauge width. In addition it is necessary that this should not suppress the external play in short cars, which do not suffer any apparent appreciable shortening of the axle. There are two contradictory requirements which, in practice, do not appear to be incompatible, but which perhaps may be translated by a further narrowing in certain tyres.

In view of the diversity of conditions, according to the systems and the rolling stock which they use, it would appear difficult to suggest a formula for this reduction in width of gauge. The only thing that can be said is that, if the tyres are rolled to sections both externally and internally according to the highest value of Ri^2 to be provided, they will pass freely, but without play, in the track and do not call for any other modification of the gauge than that conditioned by the apparent shortening of the axle : a mean will be taken between the longest and the shortest vehicles, which will probably lead to a gauge reduction of 3 to 6 mm in the tightest curves of each system. A small amount of play will be added to the external and internal clearance of the track by sufficiently reducing the two faces of the tyres.

It will be noticed how severe is the requirement of the 34 mm groove and how slight a thickness is allowed for the flanges of the cars which may reach a high value of the variable Ri^2 in the curves.

One could have found all these results by considering the *apparent contour of the tyre* (fig. 9) :

What actually happens when a tyre designed from the section of the rail using the variable $Ri^2 = 4$ mm, for instance, assumes in the track a superior obliquity j, such that its apparent contour must be drawn with a variable such as $Rj^2 = 6$? This apparent contour then becomes the transformation of the rail by the variable $(6\text{-}4) = 2$, i.e. it becomes, at least in part, the interior transformation of the section of the rail using the variable 2.

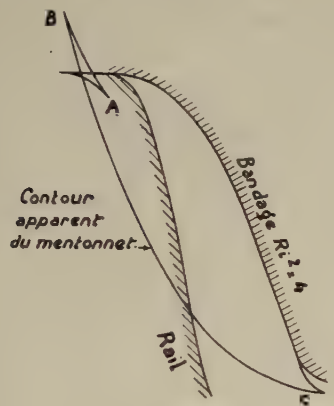


Fig. 9.

Explanation of French terms:
Contour apparent du mentonnet = apparent contour of the flange. — Bandage Ri^2-4 = tyre Ri^2-4.

But when one plots a diagram, it is seen in fact, that this only shows a small part of the features A B of the apparent contour without influence and the predominant influence is no longer the concave part of the section of the tyre, but quite simply the lower round off of the wheel flange and which shows the apparent contour B C: it is by this round off (bulge) that the tyre will touch the rail and will find its distance from the rail is controlled. It is therefore desirable to design the transformation of the flange using the variable 6 and it is confirmed that the former encroaches on the rail IC^2 by 2.2 mm. Consequently it becomes necessary that the section of the tyre should be moved back 2.2 mm, i.e. that the tyre should be reduced by that amount on the outside.

At the guard rail side, placed higher than the rail, would be found the 3.1 mm which we have already mentioned.

It should be understood that at this point the effect of the apparent shortening of the axle due to its obliquity in the track comes into play.

7 *b*). *Case concerning railways and coupled axles.*

Possibility of judiciously limiting the increased width of gauge.

Everything that has been said of the tramways remains true of the railways, but considerable practical differences must be taken into account :

1° the railways in practice run over curves which are much less tight than the trams and we have stated that the values of Ri^2 do not exceed : on the principal systems 1 mm for locomotives, 1.8 for long coaches with two axles, 3.5 mm for the bogies; on the 1 m gauge tracks : 3 mm; and on the 60 cm gauge : 2.5 mm;

2° the railways do not have grooved rails, save in exceptional cases. On systems of general interest, this only happens at level crossings, in special track installations and at maritime ports. But in all cases, the grooves are much wider than those in tramways (at the ports they go up to 70 mm with a rail S E I 70 × 70), or in cases calculated according to requirements. The methods for the lay-outs which we present or which have been presented enable us to know with precision the *influence of the obliquity of the axles on deciding the dimensions of grooves for changes of track,* which are usually studied at close quarters;

3° on the other hand, the railways have to run locomotives having more than two axles coupled and thus presenting very special new requirements.

We shall not return at this point to the numerous methods already known for studying the guiding into the track of these units, whether they are controlled or left free by the bogies or bissels with which they have to work. We would merely point out that once their obliquity in the track is known, the method of the apparent contour of the tyre or the transformation of the rail will allow the true space occupied in the track by the tyres to be known, or to design tyres which will maintain them longer when protected against the double contact. This may also be of interest to certain mountain railway engines having 5 axles coupled, the leading axle of which is particularly harmful to the track, whether it does the guiding or not.

Altogether when it is a question of railways, and to the extent that the lines are more important and the curves of greater radius, the consideration of the apparent contour of the tyre is only of contributory interest : it introduces a decimal, but then very accurate, to the thicknesses of the flange that have to be taken into consideration. It also introduces complete certainty regarding the contacts which may take place between a tyre and a given rail when it is necessary to study a particular material : long railcars, cars with 4 parallel axles, like certain railcars or certain wagons having long steel girders.

It could also allow — on account so to speak of — « no ground for action » of *judicious limitation of gauge-width on curves,* for which different railway systems practise such different rulings, often very exaggerated we think, and to know exactly how much play is available for each axle of the vehicles that are the most difficult to lead into the tracks. We think that in many cases the increased gauge width is dictated by the fear that the wheels cannot be guided into the track on account of the horizontal section of the flanges through the plane of rolling : the working diagram of which is somewhat delicate and uncertain, *too much* has been done in the fear of doing *too little.* The result is too great an angle of entry and a freeing of the movements of vehicles which we believe does more harm than good. It would seem easy to make some tests, followed in a contrary sense, in the systems which have the most ample formulae for determining the gauge spacing.

How the tyre engages the rail.

As was stated at the beginning, an observer who succeeds in fixing his eye exactly on the rail and observes the tyre from a distance, will see the contacts of the rail and the tyre in the form of contacts between the section of the rail and the apparent contact with the tyre (fig. 10).

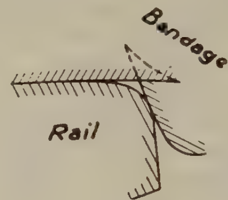


Fig. 10

Bandage = tyre.

There may be two contacts if the apparent contour of the tyre is more concave than the section of the rail, and particularly if the angle of approach is such that the apparent contour is angular. Generally speaking, and specially in the last mentioned case, the two contacts are of a very different nature : a first contact, the highest, occurs at the tread of the rail; it lies in the vertical plane of the axis of the axle or very close to it and on or close to the instantaneous axis of rotation; it is the part which transmits the vertical load from the axle and forms its actual point of support.

The second contact on the cheek of the railhead or on the round-off. It is not adapted to transmit more than a fraction of the weight of the axle, but it is capable on the other hand of transmitting an important part of the transverse pressure. As moreover, this is produced in front of

or behind the vertical axis of the axle, and at some distance away, in proportion to the inclination of the section at this point, it is relatively distant from the instantaneous axis of rotation and forms a strongly frictional contact, not to say abrasive.

It is on the tight curves, where the inclination i and consequently the factor Ri^2 are the greatest and where the front wheel on the outside of the curve attacks the rail with the greatest persistence, that one observes most clearly that it acts like a grinder or file.

We have had occasion to verify these points on a mountain railway having very tight curves in the south-west (line from Bertholène to Espalion, curves of 150 to 180 m radius).

The operator had the happy idea of placing on the rails sheets of fine emery cloth and at other points, sheets of carbon paper. The passage of the wheels (fig. 11) left on these different sheets two imprints: the first in the form of a wide band (15

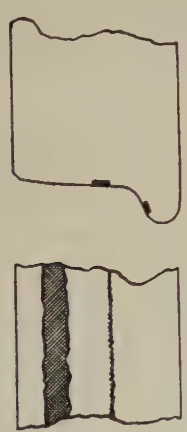


Fig. 11.

to 30 mm) slightly marked; situated at the right hand of the rolling table; the second traced lower down on the flank of the head of the rail in the form of a narrow, well-marked band, running, till the sheet was cut, which according to all the evidence corresponds to the second contact. Between the two the sheet had not been touched, and the tyre of the wheel had itself two zones marked with carbon with an intermediate portion intact. This shows clearly the existence and the independance of the two contacts. Another interesting detail, the machine was stopped on the sheet of emery cloth and taken back: the two traces did not stop at the same point; the abrasive trace, which had cut the sheet, was 35-40 mm in advance of the rolling trace, a fact which could have been foreseen.

In general, it may be said that the tyre is a tool which attacks the rail in two ways: at its first contact it acts like a press or rather like a roller, exercising more especially a crushing action; by the second contact, it acts like a mill and removes the material much more rapidly.

It would no doubt be interesting to be able to take a film of the two sections of rail and tyre in contact during the motion of a vehicle: showing the speed at which the contact is made, how long it lasts, and how it varies [1].

One realises easily enough what should definitely be the wear of the rail when studying Plate I and even more when examining Plate II where the cylindrical rim of the trams makes the phenomenon still more noticeable: if one imagines a wheel which moves to make contact with the rail at different angles of approach, it is probable that it will approach the rail from the sharpest angle, i. e. by its most outstanding apparent contour Ri^2, at a

[1] The experiment will present difficulties: it would be necessary for the vehicle in question to drag along the rail and nearly at its contact, in front of or behind the wheel and very close to it, an inclined mirror, cut out to match the section of the rail and reflecting its rays of light into a camera fixed to receive them.

The quasi permanent contact between the mirror and the rail while the vehicle freely follows the swaying (nosing) motions, is one of the difficulties to be overcome.

point situated slightly above the tangent at 70°, then the angle i and the value Ri^2 diminish; the point of contact drops slightly, in a progressive manner, remaining in fact, in the neighbourhood of 70° where the wear is localized and extends little by little in course of successive movements.

On a main line, with curves of large radius, the value Ri^2 remains steady and the range of sections which come into play are fairly restricted.

In the tight curves of the small general purpose branches, and more especially in the tramways of which Plate II show very strikingly the standard tyre and its apparent contours, the value of Ri^2 increases and they are the sections corresponding to the growing values of Ri^2 ($Ri^2 = 2... 4... 6$) which come into play, by adding the very offensive action of their inclined branch to that of the horizontal limb. Under the influence of these two attacks, which occur at an angle between them, the wear of the rail tends to take an almost angular shape or at least it is marked by a substantial reduction of the radius of curvature. An almost rectilinear lateral wearing face, showing perceptibly the slope of the tyre, is progressively developed [1].

The apparent contours of which we have shown diagrams, refer to standard tyres supposed to be new or reconditioned. It must be possible to keep account of the average condition of wear of tyres and to prepare the diagrams in accordance.

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(1) It has been observed in an enquiry made by the A. F. N. O. R. from numerous systems in Metropolitan France and Overseas, that this phenomenon is often complicated by a very clear elastic warping of the outer rail, probably due to additional deformations of the rail, of the sleeper and of the fastenings : the tread of the rail recovering its normal position is found to be worn with a slope of 5 to 10 % towards the inside (total inclination of 10 to 15 % on the plan view of the track).

Would it be of interest to modify the section of the tyre, for instance according to a transformation of the cross section of the rail but abolishing the double contact?

One may ask oneself whether it would be possible to design a section of tyre; avoiding the double contact and abolishing the resulting wear by friction. The object would be achieved if we adopted a section for the tyre having, at all points which have the same angular coefficient as the rail, i. e. at all points which may come in contact, a radius of curvature greater than that of the rail; or more exactly stated : a radius of curvature greater than that of the transformation Ri^2 of the rail obtained for the highest value of Ri^2 that the vehicle in question could realize on that line.

This result would be completely satisfied if one chose as section of the tyre, a transformation of the rail having a value greater than Ri^2 and we can conclude that :

If a tyre is rolled to a section according to a transformation of the rail under the variable Ri^2 *greater than all foreseeable value, there will never be a double contact with the rail.*

This property will only hold good when the tyre is new. However, it seems to offer good chances for minimum reciprocal wear and continued conservation of the two sections.

Pratical numerical values (useful numbers).

By way of comparison with the actual values, we give below the approximate values of the inclination which such a section would present, calculated to the lowest point of the flange, just in front of the lower round off, a round off which we have supposed to have been placed at the 3 mm radius as practised by certain systems.

It will be observed that this method of making the trace would, in general, allow for the railways, a line having a rather more falling character than the classic

	Railways for general traffic (actual value maxima $Ri^2 = 2$ or for local traffic ($Ri^2 = 3$)					Tramways $Ri^2 = 6$
Round off of rail . . . . mm	←——	—13—	——→	←—10	——→	5 (Broca)
Increased variable Ri^2, to suit the shape of the tyre . . . . mm	3	4	5.83	4	6.10	6
Total height of the tyre . . . . mm	←——	———	—30—	———	——→	20
Inclination reached at lowest point of the tyre .	76°	74°	<u>70°</u>	75°	<u>70°</u>	66°

profiles and we believe that one might stick to $Ri^2 = 3$ or 4 in avoiding profiles that would be too receding when they diminish without any advantage the margin of wear of the flange. It should be understood that only after methodical tests could one venture an opinion on the value of this solution and on the coefficient of variability to be adopted for the transformation (we should say : on the number of the transformation to be selected in each type of system). These tests would alone enable us to say how long the section would remain without the double contact and whether it would be better to adopt a higher variable and a more receding flange in order to avoid the double contact during a longer period.

How will the wheels be guided without a second contact?

First, it must be pointed out that from today the second contact will as a rule not be made : in the alignments or curves of large radius, the wheels are guided by the conicity of the tyres at least so far as the latter feature is preserved, and in the limit, by the rolling on the throat of the tyre which is equivalent to a more marked conicity, while at the same time that it opposes with great force an important horizontal component, tending to displace the wheel toward the outside. The second contact only takes place when the angle of attack is sufficiently pronounced, e. g. on a tight curve.

If in such cases, one succeeds in abolishing the double double contact, it is the first contact acting by itself, which has to provide a horizontal component strong enough to prevent derailment. The above table shows what obliquity of section and what horizontal resistance can be permitted. One is thus faced with quite a normal situation, with this advantage that the inclined contact will be produced in the vertical plane of the axis of the axle, on the instantaneous axis of rotation itself, and hence with the minimum of friction and of the tendency for the flange to mount the rail (fig. 12).

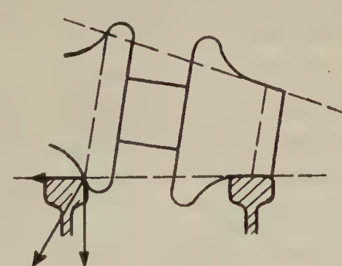

Fig. 12.

We think that such tests continued on this type of tyre would indeed be worth the trouble of carrying them out.

It will be observed that unfortunately no correlation is obligatory between the plane of contact, supposed to be normal to the resultant of the forces and the radius of

the wheel at this same point of contact, determining its instantaneous turning circle at the moment and determining, with the turning circle of the other wheel, the cone on which the axle runs and which converges more or less with the centre of the curve.

The two running radii which should ensure geometrically the convergence are the same for all speeds, but the inclination of the contact which receives the horizontal component of the forces may not at all agree mechanically with the speed and with the centrifugal force of the vehicle which is travelling. This vehicle is the forced towards the outer or towards the inner rail and tends to become displaced from the geometric position called for by the curve, to say nothing of the stresses imposed by the chassis, which will scarcely permit a simultaneous convergence of several axles. At very high speeds, the axle rests definitely on the outer rail; at very low speeds on the inner rail. At average speeds, it is probable that there will be fluctuations about an average position, fluctuations which would appear to us to be rather problematical for submitting to calculation, in view of the numerical data so numerous and uncertain which govern the problem; only by making a record could one endeavour to set particulars of these movements.

Present research to prevent yawing oscillations of the rolling stock.

The axles, which have had a run of 50 000 km (31 000 miles) have developed a certain hollowness (concavity), which on the rail tracks, appears to be equivalent to an exaggerated conicity. At that period, it was observed that at speeds above 105 km/h (65 m p. h.), which occurred with increasing frequency, a very rapid and violent transverse nosing motion was set up, known as the « sifting motion ». To get over this, experiments were made with bogie tyres of only slight conicity and a very small radius at the throat, and systematic efforts were made to guide the wheels by means of double contacts : this is exactly the opposite of what is called for by the foregoing investigation.

But it was observed that after 70 000 km (43 500 miles), the tyres reverted to the standard section and to the « nosing » or « sifting » motion : it would mean that the tyres would have to be turned up again after running 70 000 km instead of after 200 000 km (124 000 miles). This was considered too heavy a task; it was given up, at least in France and, resigning ourselves to the violent movement of the bogies, the engineers concentrated on preventing resonance between the movements of the bogies and the vibrations of the bodies of the cars by stiffening the latter especially by diagonals attached under the planking.

The research undertaken on the double contact failed to produce a lasting solution.

Would it be necessary in addition to alter the design of the cross section of the rail?

Since to obtain a reasonable cross section of the tyre one might resort to a transformation of the rail cross section, one has to ask oneself whether there are any rail sections that would provide improved tyre sections.

We do not think that the problem allows for many variables, and that the only question that should be considered would be a correct choice of the curvature of the round-off of the rail.

One might for instance, think of enlarging the round-off of the rail. A width of rail-head, almost classic of 65 mm would for example permit two round-offs of 20 mm, while retaining a tread of very large radius (of the order of at least 200 mm) having moreover a width of 25/30 mm. If we take the transformation of this rail for $Ri^2 = 3$ as cross-section of the tyre, the latter would have at its lowest point (27 mm below the tread) an inclination of about 70° 30′.

Its throat would have a radius permanently greater than 20 mm and increasing rapidly as it descends towards the flange.

Such a tyre will only stress the round-off of the rail by a fairly reduced load per mm². As a matter of fact the test would seem to be difficult to carry out, for lack of suitable rolls for producing such a rail. Moreover there seems to be no need to undertake this, in view of the suitable section of the existing rails with round-offs of 13 mm and sometimes 14 mm in Alsace Lorraine.

SOME NUMERICAL VALUES ADOPTED IN TRAMWAY PRACTICE.

THE RATIONAL DOUBLE CONCAVE WHEEL FLANGE.

At an earlier stage, we criticized the heavy standard flange of 1920 and have shown that in order to use the heavier flanges suitable for use with existing grooved rails, it would be necessary *to roll the tyre, externally and internally, in accordance with the transformations of the rail section* used with a variable Ri^2 superior to all the variables Ri^2 apt to be reached by the given vehicle, as a function of its fixed wheelbase, of its wheel diameters and of the curves that it has to negotiate.

In order to adopt such tyres with *rational double concave wheel flanges*, it will be suitable to consider the Broca rail I C², its different transformations, and to examine the space left between them for the flange. Plate III shows transformations for the values of Ri^2 from millimetre to millimetre and leads to the following results :

For Ri^2 = mm	2	3	4	5	6
Possible thickness of the flange at 4 mm below the level of the tread . . mm	27.0	25.3	23.7	22.2	20.9
Cross section of the flange above this level . . . . mm²	338	292	251	213	177

At the same time it is well to consider the values of Ri^2 which should be truly allowed for.

Each system should examine its longest vehicles, its sharpest curves and taking into account also the diameter 2 R of the wheels concerned, should see which section of flange should rationally be provided. A vehicle of long wheelbase and having large wheels might require a special section.

We have made the calculation for a certain number of systems and we have set out the positions according to the following figures :

Designation of System	T	M	L	B		L'	N	D
Min. radius of curves . . . . C = m	15	15	16.20	18	18	19	17.28	22
Rigid wheelbase of cars . . L = m	3.20	3.0	3.0	3.70	3.40	3.0	2.50	3.0
% value of $i = \frac{L}{2C}$ . . . . . %	10.65	10	9.4	10.3	9.45	7.9	7.25	6.8
‰ value of i^2 . . . . ‰	11.4	10	8.8	10.6	9	6.3	5.25	4.65
Diameter of wheels . . . 2R = mm	811	880	890	835	912	873	898	848
Value of Ri^2 . . . . mm	4.63	4.40	3.45	4.56	4.11	2.73	2.36	1.97

It will be noted that certain systems are very easy to work by using $Ri^2 = 3$ flanges. Others, at least for the long vehicles referred to above, must use flanges $Ri^2 = 5$ having a thickness of only 22 mm, much thinner, and allowing for re-turning, give much shorter service. On this account the flanges must adjust themselves, by quick wear, to the required dimension, while at the same time the rail itself is subject to premature lateral wear.

Incidentally, we would point out, the direct application to this study of the properties which we have explained above : when a flange designed according to section $Ri^2 = 5$, for instance, runs on the track with obliquity j such that at that instant $Rj^2 = 4$, its apparent contour, which at the same time is the space it occupies, is the section $Ri^2 = 5 - 4 = 1$: as shown on Plate III. We can see from this the convenient service which a diagram of this type has to offer.

Note I. — The research which has just been made on a grooved rail is no valid for the other rail unless the distance of the two rails is in harmony with the gauge of the rails at right angles to the track, i. e. with the length of the axle less $\frac{1}{2}$ Ei^2. If the increased or reduced gauge of the track are not in agreement, the internal or external play of the flanges in the grooves is sufficiently reduced and it is necessary, by comparing the sections, to ensure that there will be no binding. One may either have to alter the gauge of the track, or to displace one or the other face of the tyre in relation to the spacing of the wheels.

Note II. — It is striking to note the marked reduction in the thickness of the flange caused by raising the guard rail, done with the object of reducing the risk of derailment. With the I C^2 rail where this raising of the guard rail reaches 4 mm, it causes a loss of 2 mm in the possible thickness of the flange. If the guard rail is placed 2 mm below the rail, one could give back 3 mm of the thickness to the flange; but it would be useless to go further down, since a thicker flange would not pass the narrow groove of the rails in the line.

Note III. — In the variable Ri^2 which governs the swelling of the apparent contours of the tyres, the angle of incidence (attack) i appears as a square. To this is due the interest in any action which might reduce the *angle of attack by the wheels* by cutting down the different amounts of play which give rise to it, e.g. the replacement of hornblocks by links without clearance, i. e. silent-bloc types.

A serious and general reservation.

As perfect as the section of the tyre, whether new or reconditioned might be, it must be remembered that the running surface wears away gradually thus approaching the centre of the wheel : the section of the flange likewise tends to do the same. One could indeed, in anticipation, have placed it a little too high, if this would not reduce the flange too much. But on principle, one must be prepared for the wear in service to keep the flange at the proper height, and this wear would unavoidably be accompanied by double contacts, by chattering and by wear of the rail : at best one would have retarded them as far as possible.

CONCLUSIONS. — TESTS TO BE MADE.

Definitely, if a geometrical analysis is carried far enough regarding the conditions of the motion of the axle when mounted in the track, we are led to adopt the following conclusions :

1° *the geometric details of contact* of the rail and of the tyre are now perfectly clear, whatever might be the obliquity of the axle in the track, i. e. the angle of attack of the rails by the wheels;

2° it is easy to design the tyres *for which the double contact,* its wear and its defects, are *avoided or greatly retarded.* It looks as if it would be interesting to experiment with a certain number of tyres of this type,

particularly for rolling stock required for a sinuous mountain railway and giving rise at the present time to rapid wear and even more so for the tramways;

3° It would seem possible on a certain number of systems, and therefore very desirable, to revise and *reduce the formulae for increased gauge in the curves.* The test can easily be made with a few test curves of different radii. It will enable judgment to be made concerning wear of the track, state of the fastenings, negotiation of curves, wobble, by the coaches, the resistance on a curve (measured by dynamometer car) whether favorably affected or not : in short, whether the theoretical views that have been noted, are confirmed by experience and could be applied progressively, or whether they are contradicted, which latter would make it necessary to go more deeply into the problem.

APPENDIX I.

Determination of the apparent contour of the tyre.

We have to find the apparent contour of the tyre projected onto a plane perpendicular to the direction of the rail.

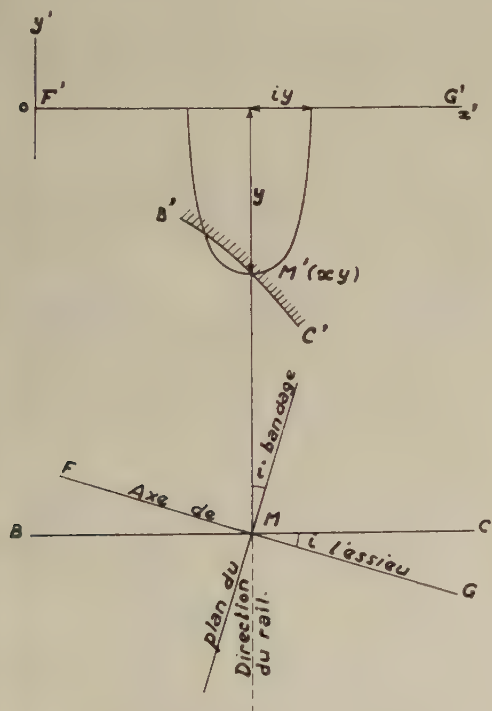

Fig. 13.

Explanation of French terms :

Axe de l'essieu = axis of the axle. — Plan du bandage = plan of the tyre. — Direction du rail = direction of the rail.

The tyre is a surface of revolution generated by a section which revolves about the axis of the axle. In this revolution, each point of the section describes a circle which is projected in the form of a very flat ellipse : the curve forming the envelope of all these ellipses is the apparent contour of the tyre. We will now determine this curve.

We show in a descriptive presentation (fig. 13) the axis (FG, F′G′) of the axle, with obliquity i always very slight in the plan of the figure (angle of incidence);

BC, B′C′, projection of the section of the tyre, which practically coincides with the section itself, given the slight value of the angle i;

MM′ a point in this section, with coordinates (xy) in relation to the axes $ox'y'$ in the figure.

It will at once be seen that the point M of the tyre belongs to a parallel of this surface of revolution, which is projected on the vertical plan of the figure according to the ellipse :

$$\frac{(X-x)^2}{i^2y^2} + \frac{Y^2}{y^2} - 1 = 0$$

or

$$E \equiv (X-x)^2 + i^2(Y^2 - y^2) = 0 \qquad (1)$$

We obtain the envelope of these ellipses by deriving the above equation in relation to the parameters x and y which are themselves linked by the equation for the section of the tyre, and by eliminating x and y between the three equations.

Thus if the equation for the section of the tyre $y = f(x)$; the envelope will be defined by the three equations :

$$E \equiv (X-x)^2 + i^2(Y^2 - y^2) = 0 \qquad (1)$$

$$\frac{dE}{dx} \equiv 2(X-x) + 2i^2yf'x = 0 \qquad (2)$$

$$y = f(x) \qquad (3)$$

From these equations, we get :

$$X - x = - i^2 y f'x \qquad (2)'$$

or by calling t the angular coefficient of the tangent to the tyre section

$$X = x - t i^2 y \qquad (4)$$

then

$$Y^2 = y^2 - t^2 i^2 y^2$$

or

$$Y = y\sqrt{1 - t^2 i^2} \qquad (5)$$

The envelope or apparent contour is then obtained by a very simple geometrical construction.

1° *Abscissa.* — Let BC be the section of the tyre (fig. 14), MS the normal at M, A the point (XY) of the envelope deducted from the point M of the tyre. Then we have in fig. 14 :

$$MQ = X - x = t i^2 y$$

but

$$MQ = t . SQ$$

hence

$$SQ = \frac{MQ}{t} = i^2 y.$$

In this value $i^2 y$, i^2 is constant and y only varies with point M. It is therefore sufficient to carry a height $i^2 y$ over to the right of each point M between its normal MS and its horizontal MQ thus obtaining the abscissa for point A.

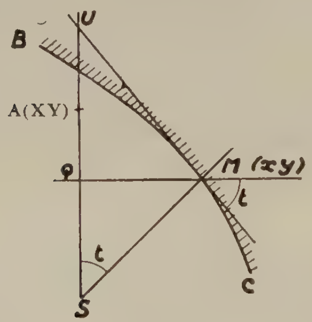

Fig. 14.

Since the factor y varies very little over the whole active height of the tyre, from 30 mm in practice, one can admit for SQ the constant value Ri^2, R being the radius of the wheel for a runway increased by 15 mm.

2° *Ordinate.* — On the other hand, AQ $= Y - y$. But we can write :

$$Y^2 - y^2 = t^2 i^2 y^2 = (Y + y)(Y - y) \qquad (1)$$

or

$$Y - y = \frac{t^2 i^2 y^2}{Y + y} = \frac{(X - x) t y}{Y + y}$$

or

$$\frac{Y - y}{X - x} = \frac{ty}{Y + y} = t \frac{y}{2y + M} = \frac{t}{2} \frac{1}{1 + \frac{MQ}{2y}}$$

By neglecting MQ in relation to the wheel diameter $2y$, this being permissible in the zone equal to the height of the wheel flange in question we may take :

$$\frac{Y - y}{X - x} = \frac{t}{2}$$

and the point A of the envelope is the centre of the segment UQ. Strictly speaking, it would be closer to Q by a quantity between 0 and 3 % of the value UQ and the curve, which we shall trace, will be rather too much of a falling curve.

3° *Tangent.* — If starting with equations (4) and (5) we calculate the value of the angular coefficient of the envelope at A, almost exactly :

$$u = \frac{t}{\sqrt{1 - t^2 i^2}}$$

Since i is very small of the order of 1/10 to 1/20, $t^2 i^2$ is very small within the limits under consideration and we can put $u = t$, i. e. that the tangents at M and A of the tyre and of the envelope are parallel. This is not strictly accurate, in the lowest zone of the apparent contour, except in the degree or value of $t^2 i^2$ that may be neglected as compared with unity.

In short, the construction which is very close to the apparent contour is a simple anamorphosis of the section of the tyre and is calculated by the three following operations (fig. 15) :

— tracing the normal to each point M of the section of the tyre, we take the subnormal height SQ $= Ri^2$, which is practically constant for a given value of i (R, radius of the wheel increased by 15 mm; i, obliquity of the axle with respect to the rail);

— on the vertical SQ, we take QA $=$ 1/2 QU; A belongs to the apparent contour;

— the tangent in A to the apparent contour is parallel or very nearly parallel to the tangent to the section of the tyre.

In this way we get a very simple construction, which may be made with the rule and square, without having recourse to compasses. It is done very quickly.

First property. — The section of the tyre and its apparent contour are reciprocal curves.

It will be noted that this *construction* is identical with that referred to earlier in connection *with* the construction for the meridian envelope for the *rail* rotating about the axle.

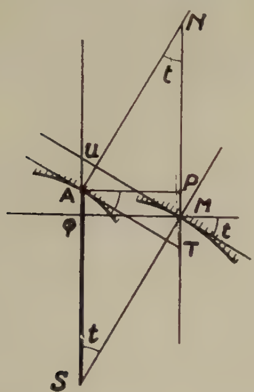

Fig. 15.

As in this case, the points A and M are reciprocals : we have taken care to use the same lettering in the figures in order to mark their identity.

Second property. — It is easily verified that *all the transformations* Ri^2, Rj^2, etc., *of the same tyre are transformations each of the other*; the transformation Rj^2 of the initial tyre is a transformation $R(j^2 - i^2)$ of the transformation Ri^2.

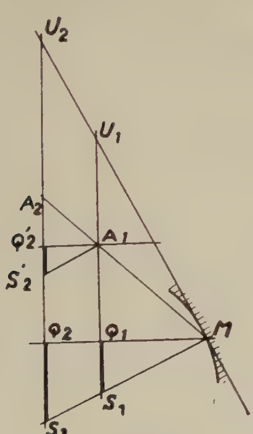

Fig. 16.

In fact, if we take (fig. 16) the points A_1 and A_2 of the two transformations having for variables $Q_1S_1 = Ri^2$ and $Q_3S_2 - Rj^2$. Then figure 16 at once shows that :

$$\frac{Q_2'S_2'}{A_1Q_2'} = \frac{Q_1S_1}{MQ_1} = \frac{Q_2S_2}{MQ_2}$$

$$= \frac{Q_2S_2 - Q_1S_1}{MQ_2 - MQ_1} = \frac{Q_2S_2 - Q_1S_1}{Q_1Q_2 = A_1Q_2'}$$

hence $\qquad Q_2'S_2' = Q_2S_2 - Q_1S_1$

APPENDIX II.

True position of point of contact.

The point of contact rail-wheel which is projected at A (fig. 17) and which corresponds to point M on the section of the tyre, is not reproduced in the vertical plane passing through

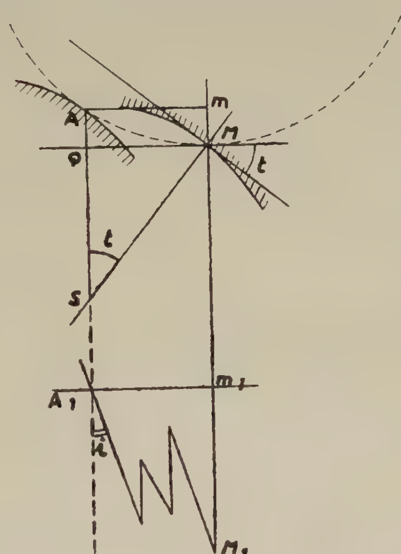

Fig. 17.

the axis of the axle, but in front or behind it, at the point where the parallel M of the tyre passes at the level A. Since the plane of this parallel forms angle i with the plane of figure 17, the distance of point A to the plan of the figure is :

$$M_1m_1 = \frac{A_1m_1}{\text{tg } i} = \frac{Am}{\text{tg } i} = \frac{MQ}{\text{tg } i} = \text{pratically } \frac{MQ}{i}.$$

If the angle of attack of the tyre with respect to the rail is $\frac{1}{20}$ or $\frac{1}{50}$, the distance of contact A to the plane of the figure will be 20 or 50 times MQ.

It will be noted that the multiplier $\frac{1}{i}$ will not be the same for all the wheels which have, in the nieghbourhood of the rail, the same apparent contour of variability $Ri^2 = K$: it depends only on i and being $\frac{1}{i}$ or to $\sqrt{\frac{R}{K}}$, it will be proportional to the square root of the radius of the wheel. A wheel of 2 m dia. will produce contacts $\sqrt{2}$ or 1.41 times more distant than a wheel of 1 m dia.

On the other hand we have

$$MQ = QS \text{ tg } t = (Ri^2) \text{ tg } t.$$

But Ri^2 is a constant for an obliquity given by the axle : MQ is therefore proportional to tg t, i. e. to the inclination of the tyre at point M, and since the *distance from the contact* is $\frac{MQ}{i} = \frac{(Ri^2)}{i}$ tg t, *it will be proportional to* tg t (fig. 18).

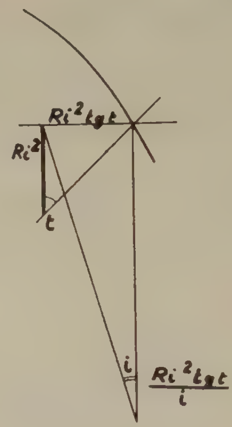

Fig. 18.

[621 .135 (01]

Simple errors and paradoxical truths relative to hunting movement,

by M. Robert LÉVI,

Directeur des Installations Fixes de la Société Nationale des Chemins de fer français.

(*Revue Générale des Chemins de fer*, December 1951.)

INTRODUCTION

In railway matters, one of the most difficult subjects to understand is that of hunting. This can be defined as the complicated movement which affects axles of vehicles independently of their rotation and vertical oscillation, i. e. the combination of tranverse movements of the axles and the variations produced in their positioning.

The measures taken to eliminate hunting have therefore considerable interest, since they govern both the attainment of very high speeds and the comfort of passengers, apart from the fatigue of rolling stock and permanent way components, and, even to some extent, of structures. Numerous authors have concerned themselves with this problem, either in theoretical surveys or by experimental research. The *Revue Générale,* in fact, published no fewer than ten articles on this subject between 1931 and 1940 [1].

The author of this note prepared before the war a fairly long article in which, after some general remarks on periodic movement, he gave the main results of theoretical surveys and experimental research carried out by the former Etat Railway in which he participated. Circomstances then prevented the publication of this article; in fact all such articles because of the complexity of the problem and the limited interest of the reasoning, are capable of reaching only a very limited public; moreover, specialists who enter such a contentious sphere tend to rely only on those observations and theories of which they are personally convinced, and consequently follow the pure doctrine of Descartes by ignoring all ideas previously held.

It is quite certain, however, that the study of hunting has progressed little for the past 30 years, since CARTER [2], largely

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[1] See *R. G. C. F.,* December 1932 : « La résistance de la voie aux oscillations de lacet des véhicules », by M. BLONDEL; January 1933 : « Etude sur le lacet des véhicules. Un nouvel appareil d'auscultation des voies à la Compagnie d'Orléans », by M. MAUZIN; « Addition d'un attelage entre les bogies aux locomotives électriques du type BB de la Compagnie d'Orléans »; March 1934 : « Mesure des efforts latéraux des véhicules sur le rail », by M. MAUZIN; February 1935 : « Etude relative au contact des roues sur le rail », by M. R. LÉVI; June 1937 : « Efforts transversaux exercés sur la voie par les locomotives 221 A et 231 D de la Compagnie P. L. M. », by M. CHAN; « Moyens d'améliorer la tenue en marche des locomotives », by M. CHAN; January 1938 : « Utilisation dans les Chemins de fer français des appareils piézo-électriques pour la mesure d'efforts », by M. MAUZIN; February 1939 : « Etude expérimentale et théorie du mouvement de lacet des locomotives en courbe », by M. LANOS; July 1939 : « Quelques observations au sujet du mouvement de lacet des locomotives en courbe ».

[2] In particular this work does not appear to have been known in France. It is therefore not surprising that M. Yves ROCARD should, in 1934, have followed all the steps in the problem, and moreover dealt with it in a similar manner. See « La stabilité de route des locomotives », by Yves ROCARD, with a note by M. Robert LÉVI (*Actualités Scientifiques et Industrielles,* Nos. 234 and 279. Herman & Cie. publishers).

unknown, opened a line of thought which should have been productive. The contents of his survey are worth development, at least in so far as they can contribute to the correction of persistent errors or as a guide to further research. This will be the purpose of the article which follows.

As the author, however, proposes less to provide demonstrations for expert investigators but rather to set forth some simple ideas for readers whom the subject attracts and at the same time repels, he will confine himself to a survey of some considerations selected from the more revolutionary ones. This arrangement will explain the often paradoxical appearance of the article, for which the writer apologises in advance.

I. Vehicles do not generally conform to the track.

As a first generalisation, it is true that vehicles must follow the general direction of the line. This is, of course, a truism.

This could be said equally of an automobile on a roadway and it cannot be denied that this movement does not reproduce the detailed profile of the road.

To be more precise, this comparison explains causes of hunting and its main characteristics. Just as the body of an automobile may be nearer to or further from the roadside, owing to the flexibility of its tyres and springs, so the centre of an axle deviates, either to right or to left, from the axis of the track, and the suspended masses do not remain vertical to the unsprung masses to which they are connected mechanically. In both cases, the phenomena of elasticity come into play; in the case of a railway, these are the deflection of the sleepers, the canting of the rails, the bending of the wheel centres and the flexibility of the links between oil boxes and frame, as well as between frame and body; this is additional to the side play of the tyres on the running surface of the rails. Finally, rolling complicates further the hunting movement.

None of these causes can be *entirely* ignored. It is indeed of prime importance to assess, in one way or another, the order of importance in their effect on the resultant movement. However, numerous writers have neglected to take this precaution and have thus been led to make some easy but erroneous assertions. For a description of the behaviour of vehicles on a railway track, it is also as useless to ignore the friction in the areas of contact between rails and wheels, or the connection between hunting and rolling, as it is to ignore the irregularities in the track.

We will content ourselves here with a result of the theories and experience, which can no longer be disputed.

If it is true that in a general way, trajectories are closely parallel to a fixed line, defined by the layout of the track, they deviate, as a second generalisation, as if the pendulum movements moved the various masses of the vehicles, either occasionally or permanently, these pendulum movements being superimposed on the general forward movement.

It is necessary here to understand the word « *pendulum* » in its widest sense; it signifies simply that, within a short period of time each mass is drawn back to a median position.

The clearest demonstration of this principle, which is the essential feature of hunting, is provided by an investigation made in 1935; this is, so far as we know, the only investigation made for the purpose of determining exactly the trajectory of the suspended masses.

In accordance with a programme drawn up by a sub-committee of the U. I. C., trials were carried out, mainly in 1935, on the disused Douai-Leforest line, to determine the maximum amplitude of transverse oscillations of vehicles in movement.

The experimental equipment was designed by M. CAMBOURNAC, then Chief of the Way & Works Department, Nord Railway. It comprised feelers bearing on a railing, carefully adjusted to follow the axis of the track.

The most characteristic results of these tests were obtained with an Etat Fu wagon, of 5.90 m (19′ 4 1/2″) between centres, known to be very susceptible to transverse oscillation. Several tests were carried out under conditions which varied in tightness of coupling, tyre profile, and particularly in side play on the track. From these trials on straight track, it was shewn that movement of axles on track fell into two classes : below a certain speed movement was small and irregular; above this speed, there appeared to be a hunting movement with a sinusoidal form which was noticeably regular.

Body movement was in direct relation to axle movement.

Fig. 1 is a superimposition of several recordings all taken under the same conditions with the exception of speed, which varied from one test to another.

The single appearance of this diagram is sufficient to show that the cause of hunting does not rest solely on track irregularities. Assuming that the record made at 70 km (43 miles)/h furnishes a true reflection of the latter, it cannot be explained why there is no trace of it in the recording at 60 km (37 miles)/h, nor why the recording at 80 km (50 miles)/h should be quite different.

Before leaving the subject, it appears wise to stress the great advantage of the method employed on the Douai-Leforest line. As mentioned above, it appeared to be the first time that tests had been made with true trajectories. Other methods have been used to ascertain the relative displacement of certain parts, for example the relative displacement of other parts to the pivot of a bogie or to record the displacement of a wheel in relation to the

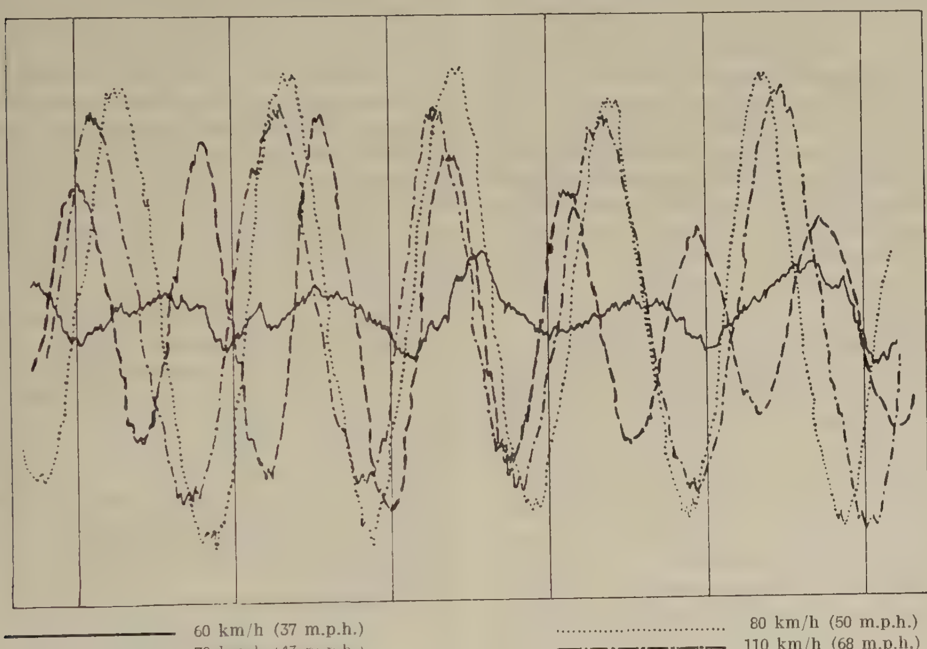

Fig. 1. — Variation of hunting characteristics in relation to speed.

rail, but this proves nothing but that they agree.

On the other hand, we have a significant indication. During trials on the line from Massy-Palaiseau to Chartres with a heavy locomotive — to which we shall refer later — a film [1] was taken of the lower part of the leading driving wheel when running over an observation zone on a curved section; this wheel, located on the outer side, should frequently have come away from the rail because the recording apparatus of the bogie showed very large movements. However, only momentary separation at very high speeds were observed. Furthermore, the cinematograph record, made to give the relative position of the rail and the wheel, shewed a squaring movement with oscillation, which corresponded geometrically to the mechanical recording of displacement relative to the various parts of the locomotive. These in fact shewed long undulations, increasing with the speed.

The amount of elastic deformation is therefore apt to conceal entirely the phenomena which we propose to investigate, if we confine ourselves to relative displacement.

The method used at Douai in 1935, however, whilst not subject to this provision, is impractical on an operating line and requires costly preparation.

The most convenient solution, in fact, is to use accelerographs to provide information. These devices do not directly record movement, but the inertia forces are easily obtained from their records, and the essential characteristics of a movement can be read from them, i. e. periodicity and intensity.

II. The inevitable character of transverse movement.

Railway tracks cannot be constantly rectilinear. There are some alignments where the middle of the axles tend to remain on the centre line of the track and some curves, where they are impelled by centrifugal force and by the weight factor in superelevation, with a preponderance of one or the other according to the speed.

This simple statement explains what happens in transverse displacement. A closer examination, however, of what happens at the entrance to and exit from curves shews, that in one part or another of these zones, there are inevitably peculiarities in the running of the vehicles which cause, not only a change in equilibrium but a sharp movement in the nature of the *thrust.*

Let us take note by placing ourselves on the track immediately after the passing of a train running from a straight track onto a curved one. We see that the side of a brake van, from being vertical, begins to slope in accordance with the transition to superelevation. At this moment, the centre of gravity of the brake van, carried by inertia, cannot acquire any transverse speed. The instantaneous movement results from the superimposing of a rise in the centre of gravity and a rotation of finite intensity around this point, which is well above the running plane. We should then see the wheels instantaneously take a certain speed to the outside of the track. This speed is proportional to the forward speed and to the rate of cancelling the superelevation.

To put it in another way, the centre of gravity which is obliged to maintain its former direction, forces the wheels in their turn to slip on the rails with a speed equal to and with an inverse sign to that which the centre of gravity has in some manner resisted taking up. The phenomenon is similar, as regards the positions in relation to the wheels, to the passage of a tram over a break of profile, the track being without superelevation. For a heavy engine entering a curve with a superelevation ratio of 1.5 mm/m the angle of this break is 7′ and the transverse movement immediately acquired is equivalent to a live force of 22 kgm if the machine weighs 100 tons

(1) This record was taken by an employee from the front buffer beam of the locomotive.

and moves at 120 km (75 miles)/h. These amounts are not small. In fact M. BLONDEL [1] has assessed the force of hunting at around 50 kgm.

HALLADE [2] was the first to call attention to the peculiarity of movement produced at the start or finish of a superelevation curve and the usefulness of a *transition* for reducing it. Whatever is done, however, the movement can in practice only be softened (this is one of the advantages of the versine method when it is skillfully used), it cannot be eliminated [3].

This is not all. Let us take the case of two curves with a short intervening straight section. The movement allowed at the end of the first curve continues as a pendulum movement and cannot be completely eliminated during the passage over the second curve, when the impulses produced by the latter add to the existing residual speed. If there is no damping, the transverse speed will be doubled and the live force then reaches four times the rate mentioned above, or 88 kgm.

It is therefore wrong to imagine that the alignment and the profile can be such that the track causes no appreciable transverse movement.

The construction of vehicles should allow them to become stable fairly rapidly after hunting motion has started, the motion for a heavy engine being assessed at some tens of kgm as a result of the inevitable characteristics of the track.

We should not wish to see in these assertions a reason for permanent way engineers to relax their efforts to provide the best possible lay-out. On the contrary, we have ourselves extended everywhere the versine method, and particularly its flexible variants which provide for very long transitions; we are convinced that these precautions, whilst they cannot prevent hunting, are nevertheless very useful since they reduce oscillation which is harmful to both rolling stock and track. There are, fortunately, vehicles whose hunting tendencies even when they are encouraged, are not to be feared, and for these the quality of the lay-out has full benefit.

III. The disadvantages of a too regular track.

For the same reasons, we consider that we cannot be accused of pursuing the paradox in stating that too great a regularity of track sometimes facilitates the development of hunting [1].

Before coming to this, let us consider the statement that in certain conditions, transverse movement of the various masses has a pendulum-like character. Conditions in this case can easily be assessed; theory and experience both allow them to be defined; these are particularly, for wagons, carriages and locomotives without guiding and non-driving axle, running on straight track at high speed and for locomotives with guiding bogies or bissel trucks, running at high speeds through curves under certain supplementary conditions such as superelevation, speed, degree of check [2] and even the condition of the surface of the rail [3] (greasy, wet, dry, sanded).

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(1) See *R. G. C. F.*, December 1932, particularly p. 440.

(2) See *R. G. C. F.*, April 1908, particularly p. 265.

(3) *N. D. C. R.* — See, regarding curves, the article « Le raccordement parfait », by M. A. CAQUOT, de l'Académie des Sciences, in the January 1949 issue of the *R. G. C.F.* (p. 1).

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(1) See *R. G. C. F.*, July 1939, particularly p. 45.

(2) See *R. G. C. F.*, February 1935, p. 101.

(3) During extended trials on the Massy-Palaiseau to Chartres line mentioned further, differences in the behaviour of a locomotive were noted, according to whether it had rained or not. M. HÉBERT, then Assistant to the Chief of the Rolling Stock Dept. of the Etat Ry. undertook trials with greasy, wet, dry and

As regards the pendulum motion, this comes from the existence of a fairly well defined period whose amplitude is not, however, constant. By and large, we may take it that the transverse movement of the various masses is defined by that of a single point of the vehicle; this simplification makes the phenomenon easier to understand, without changing it noticeably. We can then consider the centre of the wheels and assume that the tangent to the trajectory from this point and the frame remain parallel, the other masses being rigidly connected to it.

We thus arrive at a picture of hunting movement by likening it to the pendulum of a clock, the mechanism of which is still unknown to us.

Assuming that a normal clock with pendulum forms a completely true picture of a vehicle, we shall consider it as displaced from a line which follows the middle of the track. First, let us see what happens if we leave the pendulum after having moved it slightly from the vertical with our finger; oscillations start and progressively fade away because of the damping. If the initial amplitude is sufficient, the escapement comes into play and increases the movement as if the damping had become negative, until the amplitude has reached the value for normal running. If the initial amplitude is even higher, true damping re-appears until the normal regime is established (fig. 2). It can then be said that damping gives way to counter-damping, then again to damping, when increasing initial amplitudes occur.

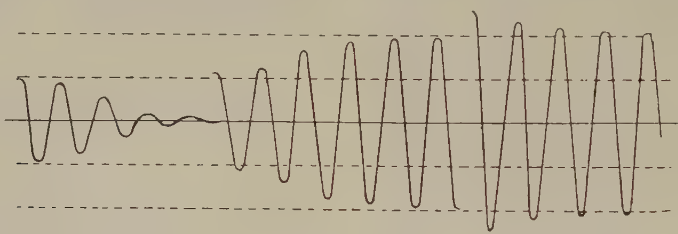

Fig. 2.

Let us now imagine that we move the clock along a simple curve; we arrive at a similar conclusion, because the forces of inertia cause movements, of greater or lesser speed at first, of the pendulum; with a slight thrust the oscillations cease, but a sharper thrust gives it a determined amplitude. A second degree of sinuosity can also start the driving mechanism, but it could equally well produce a dislocation of the oscillatory state already acquired. A third degree would do the same and so

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sanded rails which shewed the importance of this factor (fig. A).

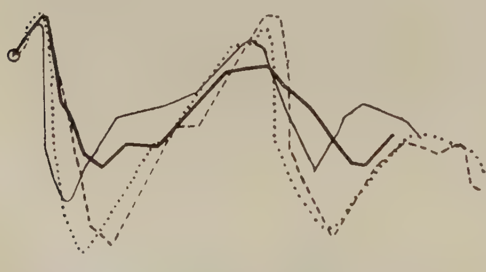


Fig. A. — Test of 241-025 locomotives with modified tyres.

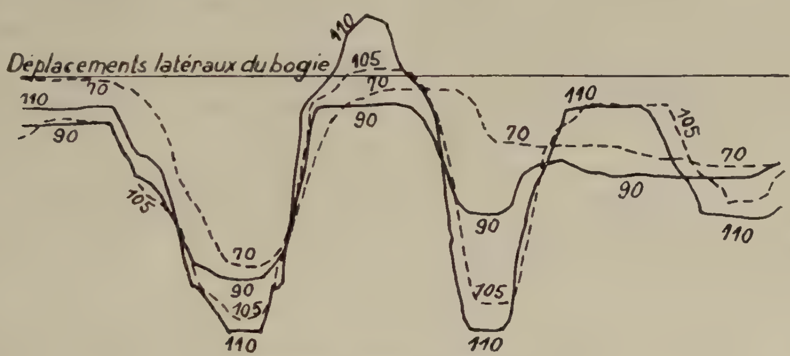
on. If the mechanism of the clock is then scarcely sufficient to overcome the passive resistance, the oscillations, once started, will be maintained only if there is no fresh sinuosity.

The behaviour of axles on rails is indeed largely similar to the picture we have drawn. However slightly a tyre may be worn, it has a concavity which follows the head of the rail; the adhesion between them acts strongly to counteract any moderate tendency to lateral displacement. With comparatively sharp oscillations, however,

c) considerable and regular when the track is very regular, apart from one special feature.

The amplitudes which separate the zones of damping and counter-damping depend on the speed, because when this increases damping generally decreases; this is shewn in fig. 3 in which the oscillation records of the same locomotive at differing speeds have been superimposed.

The confusion in observations increases still further with vehicles which do not provide such a straightforward picture. In



Scales { Distance travelled : 1.2 mm per m. / Movement : actual length.

Fig. 3.

Déplacements latéraux du bogie = lateral displacement of the bogie.

this brake force operates only for a relatively short time and the conicity on the contrary has an amplifying effect; this effect dominates. Finally, with a very strong oscillation, contact is made on the flange which gives the movement a reduced amplitude. We can then say that there are, successively, damping, counter-damping, damping.

It is consequently understandable that, where the preliminary conditions mentioned above are fulfilled, transverse movements of the same vehicle have several different characteristics, according to the configuration of the track :

a) insignificant, when the track has no particular feature or defect;

b) irregular, when the track is fairly uneven;

particular, it can be assumed that certain machines have several amplitude limits where the damping sign is inverted; there are then two conditions of the state of repeated oscillation; in general phase a) disappears in the case, but two others are added, in which the movements are :

d) strong and variable amplitude when the track is very irregular;

e) very full and regular when the track is very regular apart from one marked peculiarity.

The conclusions are to all intents the same if, for certain degrees of amplitude, the damping, without becoming negative, is sufficiently low. The table below summarises the aspects presented in this hypothesis by the movement :

Damping of hunting for amplitudes			Nature of movement
small	average	large	
heavy or light	heavy	heavy	always steady
heavy	light	heavy	usually steady
heavy or light	heavy	light	two types
light	light	heavy	fairly unsteady
light	light	light	always unsteady

In conclusion, it can consequently be affirmed that the most favourable circumstances for the development of persistant hunting motion in the running of a vehicle which is susceptible to it, are met when the track is very regular, apart from one special feature or localised defect.

bogie was 4 t. if the engine was not developing any tractive effort. It was not, however, enough to have these preliminary conditions for hunting to be produced; it was necessary, in addition, to have some initial peculiarity or defect. Curves of 800 m (872 yards) radius with a slight fall

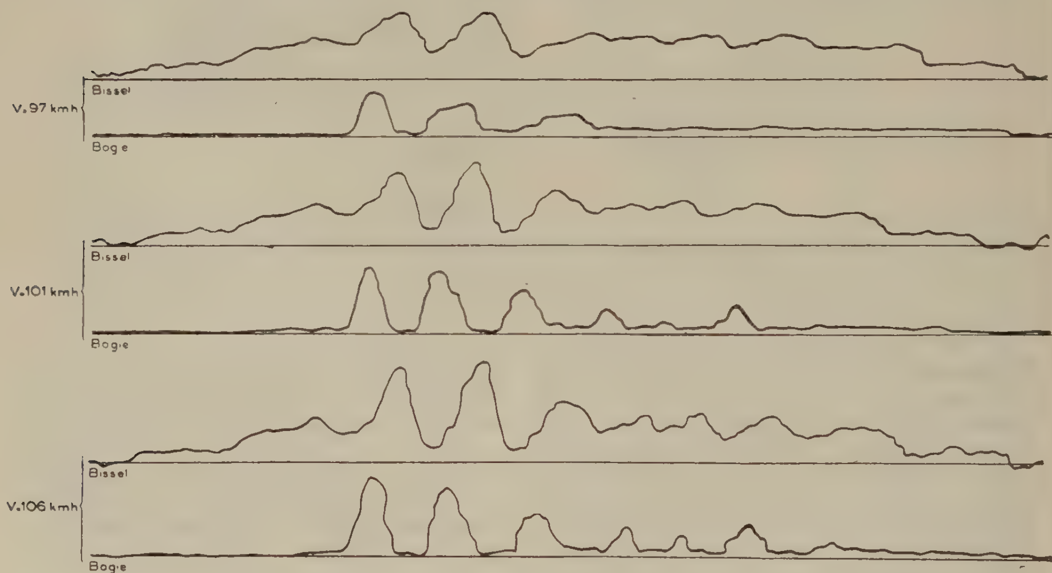
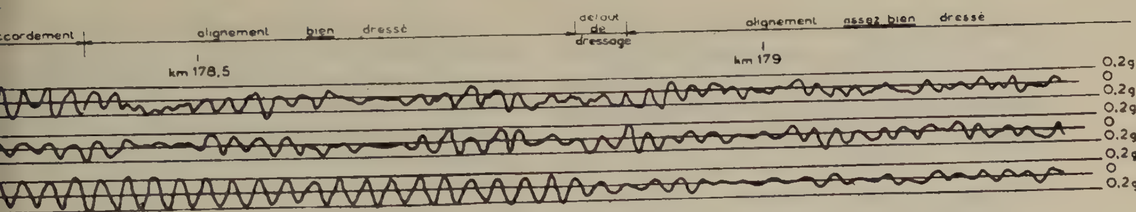


Fig. 4.

We consider that this point of view was confirmed when working a 4-8-2 locomotive in 1935. The theory, which we expounded in the *Revue Générale* of February 1935, showed that this engine was apt to hunt on curves with a radius of less than 1 400 m (1 531 yards), when the initial recoil of the were chosen on a line where the low density of traffic permitted careful trials.

Bearing in mind the principle mentioned above, we deformed one of the curves to give two strictly circular arcs, separated by an almost regular break, actually a slight curve, 3 or 4 m (9′ 10 1/8″ or 13′ 1 1/2″)



. 5. — Extract from lateral acceleration recording of leading cab of 2 D 2 locomotive on the Paris-Dijon line.

long, the level being adjusted with meticulous care.

The preparation of this trial zone required considerable work to ensure that any undesirable defect was removed. This was provided by using a machined angle which measured only to 7′, then to 14′ and finally to 21′. We will recall that the angle of 7′ corresponds to the impulse caused by the exit from a superelevated curve, well-laid but without a transition curve.

It may be mentioned that even 21′ irregularity in a curve of 800 m was quite invisible to the eye.

The locomotive used had, moreover, operated at 120 km (74 miles)/h on various lines without any very noticeable hunting and now suffered transverse movements of such a nature as to give rise to fear of an accident at any speed in excess of 110 km (68 miles)/h (fig. 4).

Following the same argument, recent trials can be quoted, using accelerometers on a CC engine. The most marked transverse oscillations were experienced on the best aligned straight sections and it ceased generally on entering parabolic curves, as if the disturbance thus caused to the movement broke up the acquired oscillation (fig. 5).

The object to be achieved, however, is not to make tolerable the secondary movement affecting vehicles particularly subject to hunting. It is to make running as smooth as possible for all trains by specifying the maximum speeds, which the mechanical design of locomotives will permit. For this purpose, the correction of vehicles particularly subject to hunting must be undertaken at the same time as the track is rectified.

IV. The drawbacks of a too-rigid track.

Hunting does not concern only driving and trailing vehicles; it affects also and particularly the track which it subjects to transverse resistance. This takes two forms: resistance to elastic deformation and resistance to permanent deformation. In effect, a transverse movement always produces elastic deformation (flexion of the sleeper, deflection of the rail) which need cause no one concern, and sometimes a shifting of track which is of a much more serious nature. It is the latter stresses and their relation to rigidity which are in question.

It is sometimes considered that hunting shocks are within fixed limits; that, in the same way, the track resists transverse forces up to another limit and that safety is assured if the first of these limits is lower than the second. Our intention is to show the multiplicity of errors contained in this simplified view of things.

The tests carried out by Mr. Blondel [1] have indicated the magnitude of these forces exerted transversely by the moving loads which are liable to produce further movement of the track under certain practical conditions. The results of these tests led to the idea that the state of a track is characterised by a certain maximum to which it is sufficient to compare a factor relative to the vehicle to determine whether the track and the vehicle are compatible.

[1] See *R. G. C. F.*, December 1932, p. 439.

The factor in question would be the ratio of transverse force to normal force on the track and could fall as low as a maximum of 0.4 in certain circumstances (newly tamped track for example).

We are opposed to this opinion for two reasons.

The first is that the resistance of the track may fall at certain places for more or less fortuitous reasons.

The second is that if the maximum figures found by Mr. BLONDEL have a clear significance when they refer to the single passage of a vehicle when it is required to know whether or not it will move the track, it no longer meets a rigid assessment of similar vehicles which may repeat similar forces at the same point; the track in that case would give way by small amounts which, in accumulation, could give rise to appreciable deformation.

In fact, the track is not an invariable geometrical entity, but is a complex, mobile and flexible, rather than resistant, indeed in one word, living. The sleepers are perfectly satisfactory with a freedom of movement which allows them to adapt themselves progressively to the forces to which they are subject, whilst resisting them.

This transverse mobility of the track, comparable to that of the small bed of a river which remains within the major bed, is put to use every day.

On the other hand, it is not at all certain that the transverse efforts exerted by a locomotive would remain within a specific limit *if the track were infinitely rigid*, in the sense in which we understand it. Tests have never been made except with locomotives running on normal track where the displacement of the sleepers has the exact effect of absorbing the excess energy and consequently of reducing the amount of transverse movement which has produced this displacement.

Instead of regretting transverse mobility of tracks, one can therefore consider that, on the contrary, it serves as a safety valve for the hunting motion.

A brief calculation allows the size of the damping effect to be assessed. If it is assumed that deformation which occurs under a vehicle loaded at 8 tons per linear metre and that the coefficient of friction on the ballast is equal to 0.4, we find that the deformation absorbs a work per square metre equal to 3.2 t/m.

Consequently 1 kgm absorbed corresponds to an area of deformation of about 0.0003 m^2 or for example a widening of 0.06 mm over a length of 8 m.

A hunting blow of 50 kgm — considered as normal by Mr. BLONDEL — is thus absorbed by a closure of about 3 mm; if this closing can be produced. If not, the 50 kgm holds good.

It is convenient to note, contrary to what one would think, the fact that local deformation is produced under an axle has not the ineluctable condition, far from it in fact, of worsening the position for the future.

Let us assume in effect that all the vehicles behave as a succession of isolated axles which all follow in the same way.

At the point P where deformation is produced, the axles struck the same rail; at the moment when the reaction of the latter was greater towards the interior of the track, the movement of the axle towards the outside of the track was at a maximum.

After deformation, the axles arriving at the point P, and not yet being subjected to the action of the rail, follow the same trajectory as in the previous situation, but as the rail causing it is further away, the contact between rail and wheel is more gentle. The elongation of the axle in relation to the track itself has decreased, and consequently, the reaction towards the interior of the track also.

In the hypothesis taken, it is thus clear that track deformation not only acts as a safety valve for transverse movement of the axle which caused the deformation, but also acts as a damper for subsequent shock at the same point. It may be mentioned that the shock is, by this fact, prolonged in the direction of travel.

This is somewhat similar to the flow of a river where the erosion of the summit of a loop tends to reduce erosion at the same point, but increases it immediately downstream. However, there is no reason to suppose that a local deformation is likely to increase the mutual reaction between rolling stock and track.

There may, on the contrary, be a disadvantage in rectifying a local defect in the track without eliminating the cause thereof. In this connection, the derailment which occurred on the open track between Saint Liguaire and Niort on the 16th April 1936 is somewhat significant.

The derailment occurred when locomotive No. 30 000 was hauling a passenger train, and it was shown that, without any doubt, the same locomotive had previously caused several faults in the track at the same spot. The day before the accident, the maintenance staff had rectified the track without ascertaining the cause of the earlier defects. The locomotive arrived at the place and as the track was not in the appropriate state, a severe spread was caused, which set up a hunting motion resulting in the derailment.

We may question, however, whether there is direct confirmation that similar facts can be attributed to a road which is too rigid. The absence of really rigid track in France prevents a categorical reply to the question, but it can be said in this respect that a derailment occurred in 1937 on a reinforced concrete trial road of the Pere Marquette Railroad [1]. This was indisputably caused by abnormal force and everything pointed to the fact that this was the consequence of hunting which was accentuated over the length of the test road to the point of fracturing the fixings; if, however, these fixings had held, it is reasonable to assume that the hunting motion would have continued to increase in violence until it fractured more robust parts, such as the rails or wheels.

[1] See *Bulletin of the International Railway Congress Association,* February 1939, p. 207.

V. The myth of resonance.

Many incidents are attributed to resonance, very often quite wrongly. This is particularly the case in the hunting-rolling relationship and the vehicle-track relationship.

The fact of resonance is not under discussion. It is known that if a body or system is susceptible to oscillation, even though it is damped, it has a certain frequency and is subjected to stresses having a close frequency, the forced vibration produced by this excitation is much greater than for any other frequency.

The term resonance must however be reserved for the state where the coincidence of frequencies concerns an external cause of vibration and an internal propensity to vibration. On the contrary, when two internal factors are co-existent, we must think of coupling. This is the position with hunting and rolling which simultaneously affect the same vehicle; the periodic movement which arises is neither hunting nor rolling, but is necessarily a composite which is formed of both at the same time. We can depict this coupling as an electrical circuit in which is inserted either a capacitator or an inductance, or both; it is quite clear that, in the latter case we cannot speak of a resonance between the two oscillations which would be produced in the absence of one or the other, since it is the same current which traverses the inductance and charges the condenser; the same applies to vehicles subject to hunting and rolling, it is the forces of inertia which condition the various equations of movement.

Another picture of coupling is given by fig. 6; two masses M_1 and M_2 are attached

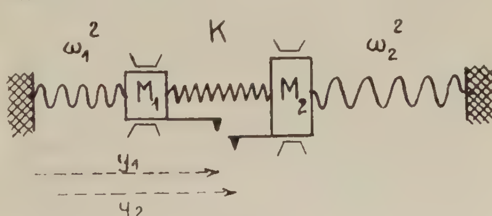


Fig. 6.

to fixed points by springs which give them pulsations ω_1 and ω_2; if these are joined together by a flexible link of tightness K, they both vibrate with a complex movement which contains two pulsations Ω and Ω'. Fig. 7 shows the hyperbolic law of variation of Ω^2 and Ω'^2 with K. With a rigid coupling, the higher curve has no practical significance and a single oscillation is manifested, whose pulsation is intermediary to ω_1 and ω_2. A slackening of the coupling is translated firstly into a drop in pulsation, then an increase in the period; afterwards a second vibration becomes possible, then preponderantly towards M_2 and this is more rapid than the pulsation ω_2.

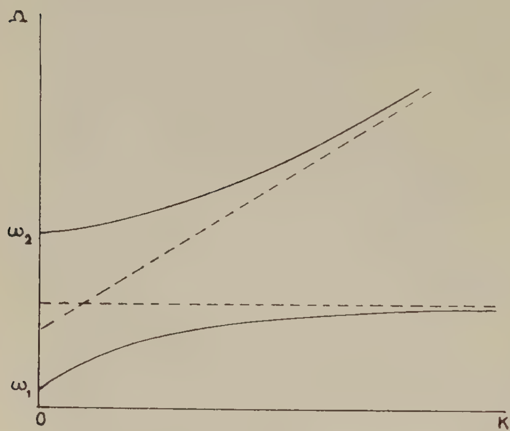


Fig. 7.

These indications are given to make it clear that there is no relationship between resonance and coupling.

As regards resonance between hunting and sinuous track, this has often been invoked as an explanation of the violence of hunting in certain cases. This is a completely unsupported explanation. It is possible that such resonance is produced under ideal conditions but no tests on an actual vehicle have ever been reported. Moreover, numerous recordings have been made with the equipment designed by Mr. MAUZIN which records simultaneously the track versines and the lateral displacement of the bogie of a locomotive; nowhere is there any agreement between the periods. This is easily understood, as the periods in question are never constant.

Fig. 8 is a reproduction of one of these recordings, selected from the more significant. Examining this closely, it will be seen that the movements of the engine under test, which were accompanied by considerable transverse efforts, were charactertised by a period generally shorter than that of the track and that there is no correlation between the amplitude of movement and the difference of phase with the sinuosity of the track.

However one can by no means exclude the possibility of moderate resonance between hunting motion and track *already deformed* sinusoidally, without fear of consequences. We say moderate, because if a vehicle finds in front of it a perfectly sinusoidal track and if the length of the curve corresponds exactly to its own, appropriate to that particular moment, the increase in amplitude will soon cause the period of hunting to be changed and the resonance will consequently be destroyed.

If then there is at a certain moment a moderate resonance between the hunting and a sinuous track, what happens? Does one, from this fact fear increased efforts between rolling stock and track and will this increase involve the risk of accentuating sinuosity which already exists?

It would be a poor knowledge of the general characteristics of resonance which would attribute to them the latter effect. Resonance in fact is so much responsible as the difference of phase between excitation and oscillation approaches a quarter of a period.

If in the case in point, the track has a series of waves, the reciprocal efforts of the track and of the locomotive are thus, in the case of resonance, at a maximum at the fixed points and at a minimum at the mid-distance between. In the case where the resistance of the track is brought into play,

spreading is not possible at the fixings; this does not result in increased amplitude, but in the displacement forward of the existing waves and the appearance in the same direction of similar new waves.

This reasoning, based on common conceptions of mechanics, is confirmed by observations made during trials carried out by the S. N. C. F. An electric locomotive having shown considerable oscillations when the shock absorbers were removed, it was put on test under fairly severe conditions. The Permanent Way Department recorded the condition of the track before and after the passage of the locomotive and the differences, which were found exactly at the fixed points, were noted.

It can thus be explained that locomotives having their own tendency to considerable hunting movement may model the track to a length of wave close to their own, without any consequent effect of these curves influencing the subsequent behaviour of the locomotives.

VI. Mutual adaptation of locomotives and track.

We may now by way of conclusion offer some remarks on the observations which have led to the opinions summarised above.

If vehicles never had any tendency to hunt, or if track were without flaw or peculiarity, there would be no problem of dynamic stability and high speeds would be limited only by the risk of capsizing over the outer rail of curves.

There have however been, particularly in the distant past, very poor roads and very unstable locomotives. It is therefore necessary to explain why there have not been frequent accidents.

Firstly it may be noted that, if the tendency to hunt at high speeds is irremovable, the engineers have introduced modifications to those types of locomotives which have shown themselves to be the worst constructed. In this way, the use of leading bogies and bissel trucks was introduced, particularly after derailment of 0-6-0 locomotives due to momentary coincidence of tearing and hunting, the first producing the unloading of an axle and the second working transversely on it.

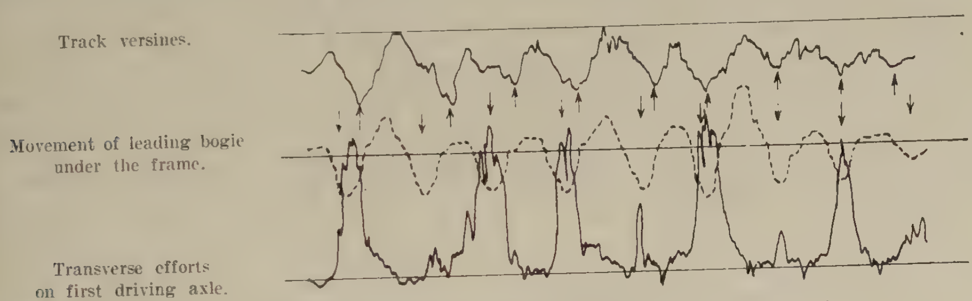


Fig. 8. — 2 D 2 locomotive on a curve of 1 200 m (1 312 yards) radius. Speed : 120 km/h (74 m.p.h.).

Concurrently, theoretical investigations showed the beneficial influence of all those factors which acted to damp out hunting motion.

Thus Mr. Marié, in a note to the *Annales des Mines* in 1909, evaluated the power developed by hunting motion by taking for each half oscillation the product of the weight, the coefficient of friction and the play in the track; moreover because he considered this calculation too unfavourable, he multiplied the result by an arbitrary coefficient K (see p. 156 of his *Traité de stabilité du matériel de chemin de fer*). On the other hand, he recognised the useful-

ness of absorbing by friction the excess energy this produced.

We may read, on this subject, in the same *Traité de stabilité,* the chapter devoted to the question of damping out hunting motion. Apart from the absorption of excess energy by the bogie centres, the author dealt with friction in the laminated springs of bogie vehicles, the usefulness of lateral displacement of a tender in relation to the engine, except in overcoming friction which acts as a safety valve, protecting the first axle of the tender and also of friction in the drawgear of carriages.

However, whatever precautions have been taken by designers of new locomotives, whether they have been guided by experience or by theory, it cannot be denied that certain types have not been greeted as very successful. The defective locomotives have sometimes been corrected but not always in an appreciable way. Thus the question set above still remains.

The reply to it will be very easy once we have eliminated a rare case : that of the vehicle which is particularly susceptible to hunting and is composed of two or more frames linked *by rigid articulation and without friction.*

The conclusion of Chapter IV for single vehicles does not cover this case; even the picture of a pendulum is not appropriate to such a vehicle from the time when the movement is strong enough to start a spread of the track under frame B, because the supplementary reaction which this exerts on the neighbouring frame A from the deformation occurring in the track is added to the forces of inertia and the reactions of the rails which are balanced for A in the absence of deformation; this supplementary force can act in the opposite direction to the effect of a deformation arising under A and consequently introduce the inverse of a braking on the movement. The fact of this phenomenon can be established by calculation and by calculation only.

The exceptional case of auto-excitation being set aside, it would seem that there is little fear of a deformation of sudden character. Thus the foregoing chapters allow the formation of an opinion on the phenomena which give rise to the appearance of a defective type of locomotive.

We will set up two hypotheses only :

— track is suitably inspected;

— engines are put into service progressively and at increasing speeds.

In these conditions, the peculiarities or local defects induce violent hunting movements which result in transverse resistance of the track being overcome. Each vehicle causing deformation settles down from this and at the same time slight unevenness is caused in the track. The same, or identical, vehicles react less by reason of the defect created, but because of their inherent tendency to hunt, they continue to oscillate beyond that point so that they may produce an echo of the first wave a little further along; the sinuosity, if it does not spread, does not get worse. As regards other vehicles, they are subject to a forced oscillation which is normally without consequence; if at the same time they take an active part by retaining this abnormal movement, they tend to inscribe on it their own period and consequently the deformations which they are apt to produce will not be in phase with the formal sinuosity; the periodicity of it will be modified and the amplitude reduced.

However — and this is the point we wish to mention specially — the deformation of the track does not only act as a safety valve for too sharp movement; it constitutes as a result a warning which makes patent the inherent defect in the vehicle causing the disturbance.

Coincidence between the introduction of a new type of locomotive and the appearance of « blows » of a repetitive kind have often been noticed; this cannot in effect fail to be noticed, and causes rolling stock engineers to remedy the defects in the vehicles or to limit their speed.

The automatic adaptation of the track

to the first disturbing movement thus sets in train a process (in which man takes part on this occasion) whereby the harmful effects of poor-running stock are avoided.

The connection between rolling stock and track is to some extent a matter of accommodation, since the two parties do not take up a fixed position in relation to each other, but give way when circumstances bring them into momentary opposition.

This optimistic view explains why railways have been able to and can still, work peacefully in spite of the apparent paradox of trains running with a considerable dynamic force on tracks which are deformed locally by the action of hunting motion which is a thousand times less strong.

[**621** .438 (42)]

British-built gas-turbine locomotive.

Metropolitan-Vickers 3 000 HP locomotive for the Western Region incorporating an open-cycle gas turbine without heat exchanger.

(Diesel Railway Traction, March, 1952.)

British Railways second gas-turbine locomotive, No. 18100, designed and built by the Metropolitan-Vickers Electrical Co. Ltd., will shortly be placed in service on the Western Region, British Railways. The locomotive was built to the requirements of the former Great Western Railway, and the work has been carried forward by the Railway Executive under the direction of Mr. R. A. Riddles, Member of the Railway Executive for Mechanical and Electrical Engineering.

The leading particulars of the locomotive are as follow :

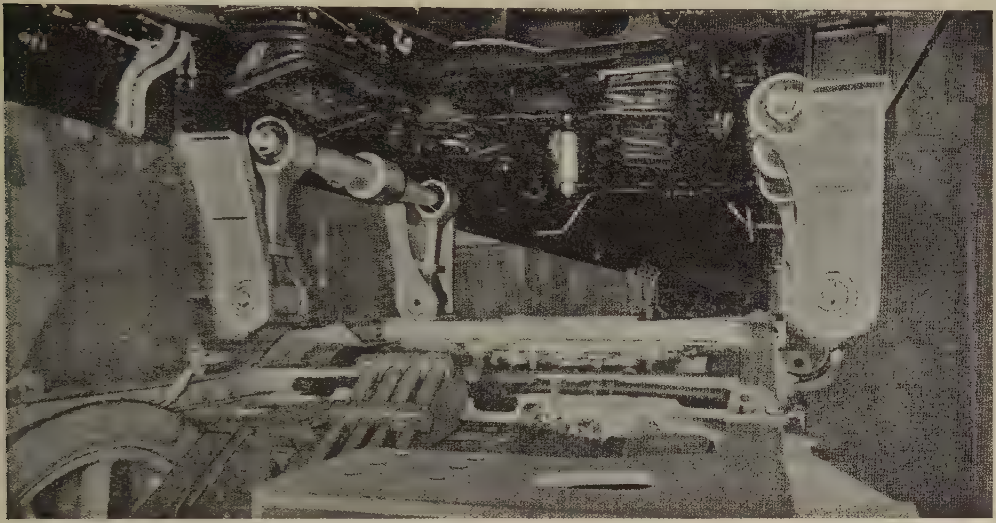
Mechanical type	Double bogie
Continuous rating of turbine.	3 000 HP
Number of axles	6 (all driving)
Weight in working order . .	129 tons 10 cwt.
Maximum service speed . .	90 m.p.h.
Maximum tractive effort . .	60 000 lb.
Continuously rated tractive effort	30 000 lb.
Length over buffers	66 ft. 9 1/4 in.
Width	9 ft.
Height from rail	12 ft. 10 in.
Wheel dia.	3 ft. 8 in.
Fuel	Gas oil

The body of the locomotive and underframe are built as a single unit almost entirely by welding. The principal members, the solebars, consist of continuous plates of deep section reinforced by top and bottom welded plates tied together at each end by the welded headstock structures. The solebars are attached by fitted bolts to the principal body members, which consist of welded assemblies. The underframe is further reinforced by cross-bracing of rolled-steel sections and by the floorplate.

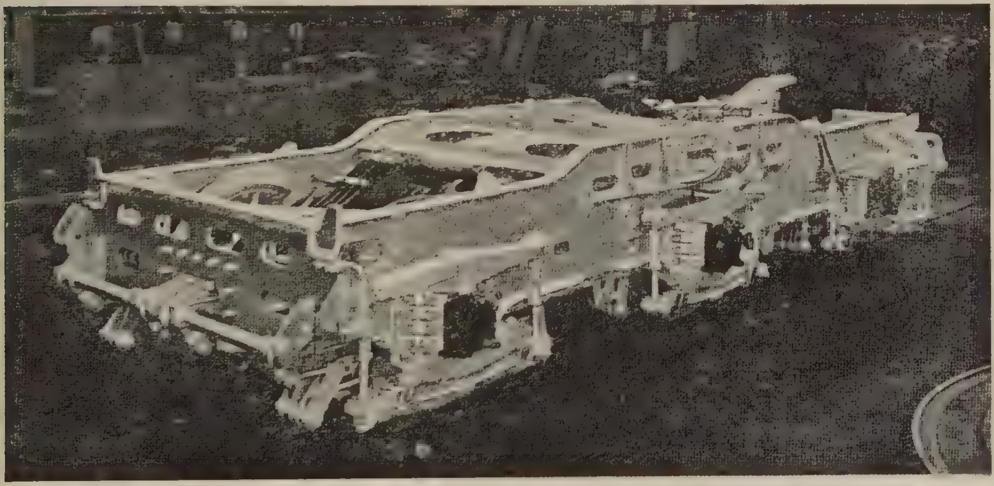
At cantrail height a ribbed curved plate section of the roof forming a rigid boom extends on each side of the body, except the cabs. The body panels are attached by welding to this boom, and also to the solebars and carlines except where space is left for air filters and louvres; the roof sections between the booms are of aluminium alloy and are suitably arranged so that equipment can be removed. Both driving cabs, which are identical, are a separate welded structure of aluminium

alloy, and are mounted on the underframe platform.

The bogies are of welded construction consisting of plate with welded flanges, the side frames being connected by headstocks and also by two cross-stays, all of welded plate. Each complete bogie frame and each main welded sub-assembly of the



Underside of locomotive before lowering on to bogies, showing the body suspension swing-link system.



One of the locomotive bogies of welded construction, showing the traction motors and spring arrangement.

body structure has been stress relieved. The body structure is carried on the two bogies by swing links attached by rubber resilient universal joints to permit controlled swing bolster action and bogie pivoting, without the use of bolsters, for which there was insufficient room between the bogie frames and within the fixed wheelbase.

Eight swing links are provided, two on each side of the bogie, and outside the bogie frame. Each link-end contains a rubber universal joint without metallic contact. The lower joint in each case is attached to the lower end of the body support brackets, and pairs of upper joints are attached by longitudinal equalising beams, in the middle of which is a rubber universal joint resting in the corresponding bogie support bracket. The resilience of the rubber joints permits the relative angular motion between body and bogies on the vertical and transverse axes and also the relative movement necessary for smooth running at high speeds.

The restoring forces are mainly those due to gravity. Damping is provided by hydraulic dampers located at four points on each bogie connected between the body underframe and the bogie frames by links having universal rubber joints. These resist lateral displacements and vertical axis rotation of the bogies relative to the body. Longitudinal reactions between the body and the bogies due to traction and braking forces are taken through a pivot pin on the body which carries a parallel motion linkage coupled to the bogie cross-stays and fitted with universal joints.

A feature of the use of rubber is that it dispenses with lubrication and the consequent rectification necessary to metallic surfaces. A further feature is the absence of metallic connection between the body structure and bogies and therefore the isolation of the body from high frequency vibrations due to track irregularities. The axleboxes are of the Hoffmann type, with two rows of rollers and one row of balls for end location; oil lubrication is provided. The axlebox wearing surfaces are of manganese steel, with hardened steel on the horn guides, grease lubricated. At each end the horn guide is of the trunnion type to permit canting of the axle in relation to the bogie.

Each bogie has three driving axles, each driven through a single reduction gear by a traction motor suspended on the axle and from a support on the bogie frame. The turbine rotates at 7 000 r.p.m. when delivering full load and drives the three main generators at 1 600 r.p.m. through single reduction gearing. This unit has two output shafts, one driving two of the main generators in tandem; the other drives the third main generator, the auxiliary generator, and the exciter.

The turbine, reduction gear, and group of generators are mounted on a common bedplate together with the main fuel pumps and lubricating pumps, and constitute a self-contained power unit. This unit is carried on three support points on the main underframe. Each of the three main generators supplies two of the six traction motors; the motors of each pair are connected permanently in parallel.

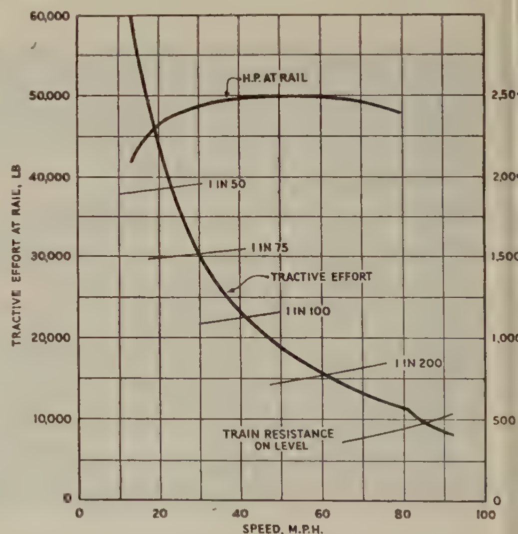
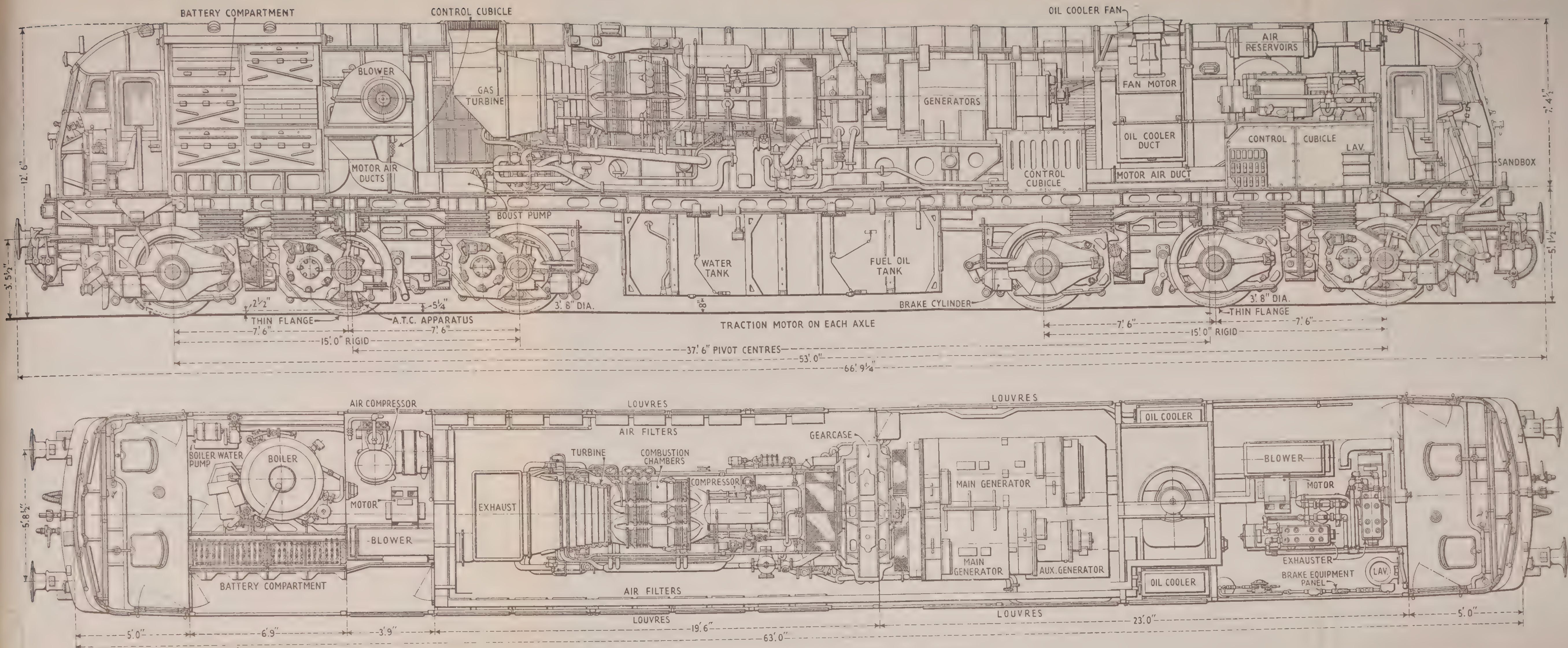
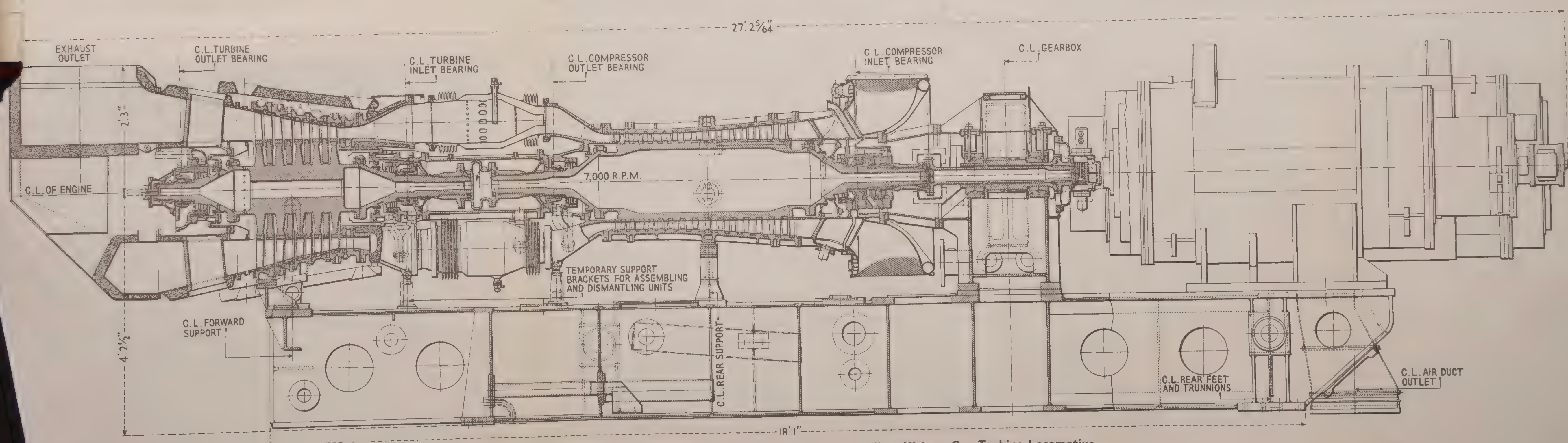


Fig. 1. — Locomotive performance diagram with an 18-coach train of 650 tons.



Sectional elevation and plan showing the layout of the equipment

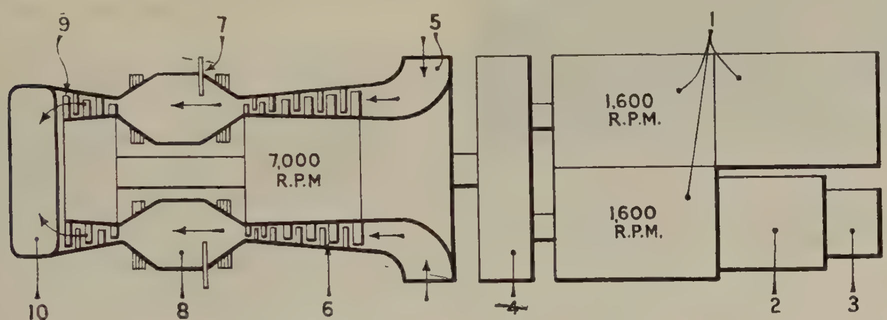


Sectional elevation of the 3,000-h.p. power unit of the Metropolitan-Vickers Gas-Turbine Locomotive

GAS-TURBINE LOCOMOTIVE BUILT BY METROPOLITAN-VICKERS ELECTRICAL Co. Ltd., FOR BRITISH RAILWAYS (WESTERN REGION).

From the turbine output of 3 000 HP an allowance of 150 HP provides for the loss in reduction gear and auxiliary equipment, leaving 2 850 HP input to the traction generators.

Over most of the speed range of the locomotive an electric transmission efficiency of about 86 % is achieved, corresponding to 2 450 HP at the rails. As shown in figure 1, this power is sufficient to give an 18-coach train balancing speeds of 85 m.p.h. on the level, and 41 m.p.h. and 23 m.p.h. respectively when climbing the cycle of compression, heating, and expansion of the air is carried out in a compressor, combustion chamber, and turbine arranged in line and built into a straight-through single unit, as shown in figure 2. The compressor is a 15-stage axial flow machine with a power ratio of 5.25 at 7 000 r.p.m. and a mass flow of 50 lb. per sec. The compressor runs in two sleeve bearings. The turbine is a five-stage unit also running in two sleeve type bearings, and its rotor is direct coupled to the compressor.



Direction of air flow shown by arrows.

1. Three main generators. — 2. Auxiliary generator. — 3. Exciter for main generators. 4. Gearbox: input shaft 7 000 r.p.m., two output shafts 1 600 r.p.m. — 5. Air intake for compressor. — 6. Compressor. — 7. Fuel-injection nozzles. — 8. Combustion chamber comprising six flame tubes arranged around the main shaft. — 9. Turbine. — 10. Turbine exhaust.

Fig. 2. — The power unit, showing direction of air-flow.

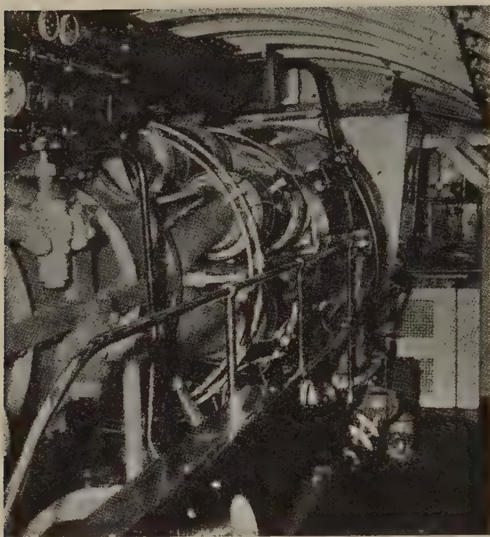
gradients of 1 in 100 and 1 in 50. A turbine full-load thermal efficiency of 19 % has been demonstrated on test. When account is taken of gear and electrical losses, the overall thermal efficiency of the locomotive becomes 16 %.

After deduction of the 75 HP required for auxiliaries, the remaining tractive power available at the wheels represents 15 1/2 % of the heat value of fuel consumed, or a fuel rate of 0.88 lb. per HP hr. At half-power this rate will rise to about 1.3 lb.

The gas turbine.

The prime mover is a simple open-cycle gas turbine without heat exchanger, and

The combustion chamber is composed entirely of heat-resisting steel and consists of six flame-tubes with axes parallel to the machine axis and connected by flexible connections at one end to the compressor outlet and at the other to the turbine inlet. The compressor and turbine cylinders are connected by a tubular member surrounding their shaft coupling, and form a single unit on which the combustion chamber is mounted. The power unit is supported on four supports with sufficient flexibility to allow for expansion. A sliding key arrangement maintains its lateral position, and the inlet end of the compressor frame is secured to the reduction gear casing which is bolted and also dovetailed to the



Interior of the locomotive, showing the installation of the power unit.

bedplate; the total axial expansion at the turbine end is about 3/8 in. The rotors of the compressor and turbine are located axially from a thrust bearing at the compressor inlet end.

The compressor cylinder is of malleable iron and the rotor is a forged-steel drum. The moving blades are machined from stainless-steel bar and the fixed blades are rolled from a similar material. The blades are retained in dovetailed slots; machined axially on the rotor and circumferentially in the cylinder. The bearings are white-metal lined and pressure oil-lubricated. A supply of compressed air is taken from an intermediate stage to a balanced piston at the inlet end for the purpose of balancing the end thrust of the combined rotors.

The turbine construction uses special heat-resisting materials, the cylinder being an austenitic steel casting and the rotor an austenitic steel forging. The blading material of the first stage of the fixed blades is of Nimonic, the second and third stages austenitic steel, and the fourth and fifth stage molybdenum steel. The first and second stages of the moving blades are of Nimonic, the third stage austenitic steel, and the fourth and fifth stages of molybdenum. The turbine bearings are similar to those of the compressor; additional cooling is provided by a flow of compressed air from an intermediate stage of the compressor.

Flame-tubes.

The six flame-tubes of the combustion chamber are secured by detachable unions to the compressor and turbine. The flame tube has an outer casing and inner primary chamber, both fabricated from austenitic heat-resisting steel. By means of metering orifices the correct proportion of the air flow is introduced into the primary to give correct combustion of the fuel fed in at approximately 650 lb. per sq. in. from the fuel jets. The remainder of the air is mixed with the very high temperature products of combustion downstream of the jets so as to produce the designed temperature at the turbine inlet.

Each flame-tube has a double fuel injector with a small jet orifice for idling fuel, and a large jet fed from the main fuel valve. Two flame-tubes are fitted with igniters, in the form of high-tension spark plugs, combined with pilot flame fuel jets. Ignition spreads to the other flame tubes through tubular connections between each pair of casings.

Method of starting.

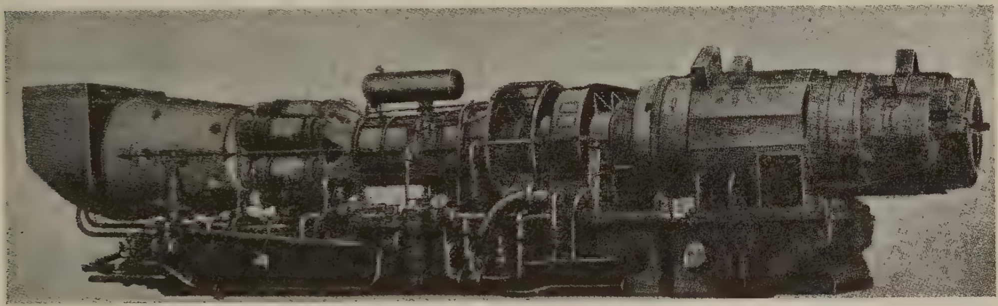
In starting, the turbine is accelerated to a self-sustaining speed by the main generators acting as motors fed from the starting battery; once the driver has actuated the starting button the process is entirely automatic. Successive steps are initiated by a sequence controller driven at a controlled speed by an electric motor. The steps in progression are : auxiliary fuel pump starts; main fuel and lubricant pump starts; igniters switched on; the automatic start-

ing valve commences to move; the turbine commences to rotate. On the turbine reaching 1 000 r.p.m. the starting valve commences fuel delivery through the idling jets of the combustion chamber.

Thereafter the fuel combustion assists acceleration, and at approximately 2 500 r.p.m. the battery automatically disconnects from the main generators and the turbine continues acceleration under its own power to about 4 000 r.p.m. From starting to the idling of the turbine occupies 65 sec. and full power may be taken from the turbine after 10 min. warming up at idling speed or at low power.

developing, excessive turbine speed or gas temperature, excessive bearing temperature, or fuel or lubricant fault, overriding controls come into operation.

The three shafts of the reduction gear lie in a horizontal plane, the middle carrying the pinion and the others the gearwheel. The pinion is made of case-hardened steel in which the teeth are ground after hardening. The gearwheel rims are of 65-72 tons chrome molybdenum steel, the teeth being finished by the shaving process; the teeth, of 5 diametral pitch, are single helical. Each shaft is hollow and rotates in two white metal sleeve bearings,



View of power unit, including combustion chamber, turbine, compressor, and generator mounted on bedplate.

On shutting down after full load running it has been found beneficial to allow a cooling period of about 10 min. at idling or low power work. On stopping the turbine an automatic barring sequence operates, which motors the turbine for a few seconds at intervals of 3 min. to equalise cooling stresses. An auxiliary lubricant pump circulates oil round the turbine bearings during this period, and is automatically stopped by a bearing thermostat at the appropriate time.

During the operation of the locomotive the turbine and generator are governed electrically to give the output selected by the driver on a master controller, and at the turbine speed for efficient operating at a particular load. In the event of a fault

and the driving shafts from the turbine and generators pass through the hollow shafts to couplings at the remote ends of these shafts. Flexibility is obtained in the drive without making the unit unduly long. Gears are enclosed in a fabricated steel gear-box, the gears and bearings being lubricated from the main turbine lubricating pump.

Main and auxiliary generators.

Two of the three main generators form a tandem unit, their jokes being bolted together. Both armatures are mounted on a common shaft carried in roller bearings in the yoke endshields. The third main generator and auxiliary generator form a

similar tandem pair; the yokes of both tandem sets are bolted side by side to make up the generator group. An exciter is overhung from the auxiliary generator. Each main generator is a self-ventilated D. C. six-pole compensated interpole machine, the field being fed from the exciter, figure 3. The ratings to B. S. S. 173-1941 for class B insulation are as follow :

Continuous rating	1 100 A, 660 V, 1 600 r.p.m.
One hr. rating	1 250 A, 580 V, 1 600 r.p.m.
Maximum voltage	825 V
Maximum current	2 200 A

The auxiliary generator and exciter are also self-ventilated D. C. machines. The former has six main poles and interpoles and is shunt-excited under the control of a voltage regulator to give 110 V irrespective of its load and turbine speed. Its B. S. continuous rating (Class B insulation) is 65 kW, 110 V, 1 280 r.p.m. The exciter has six main poles and interpoles, and is excited by three windings — a separate excitation fed from the 110 V auxiliary mains, a separate excitation regulated by the automatic output control gear, and a reverse compound excitation directly proportional to the main generator total load current. Its B. S. continuous rating (Class B insulation) is 10.5 kW, 55 V over a speed range of 1 280 to 1 600 r.p.m. The method of construction and insulation are designed to meet the arduous conditions of railway operating.

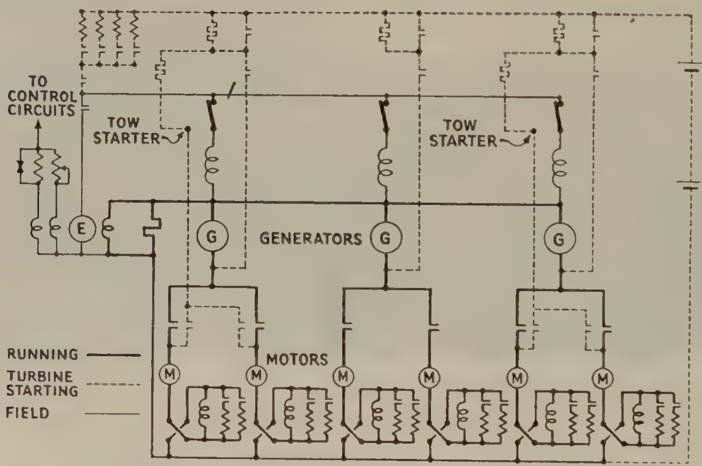


Fig. 3. — Diagram showing traction electrical connections.

Traction motors.

The six traction motors are separately ventilated four-poles series and interpole machines, each carried on its axle by plain suspension bearings; the armatures are fitted with roller bearings. The nose side of the motor yoke is suspended from a bogie transom by a link fitted with a rubber bush at each end, a form of suspension which eliminates wear, combined with freedom of movement between the motor end and bogie. The transverse location of the motor in the bogie is by another rubber resilient bushed link between motor end and bogie main frames instead of by the more conventional location by thrust faces on the suspension bearings against the bosses of the gears, with the object of eliminating the uncontrolled lateral movement of the motor along the axle and thrust wear in the bearing.

The ratings of the motor to B. S. 173-1941 for Class B insulation and ventilation air flow of 2 500 c.f.m. are as follows :

Continuous rating .	550 A, 666 V, 706 r.p.m. (33.5 m.p.h.)
One hr. rating. . .	650 A, 565 V, 580 r.p.m. (27.5 m.p.h.)
Maximum current .	1 100 A
Maximum voltage .	825 V

The drive to the axle is by a single reduction spur gearing 21-58 gear ratio 2.066 diametral pitch. The gearwheel incorporates torsonial resilience, an arrangement which cushions transmission shocks from rail to armature and provides for better riding and reduced maintenance. The gearwheel centre, rims, and pinions are hardened by oil quenching.

Auxiliary equipment.

Most of the auxiliaries are electrically operated from the 110 V D. C. supply from the auxiliary generator. The battery, consisting of 48 lead-acid cells of 384 A hr. capacity, is charged from this supply through a contactor which is closed only when the auxiliary generator is generating. Certain of the auxiliaries are battery fed and can be run only when the turbine is running.

Main fuel and lubricant pump. — Fuel and lubricant are supplied to the turbine by a pump set consisting of a 10 HP, 3 000 r.p.m. motor, battery fed, driving a feed pump overhung from the motor, and a lubricant pump mounted on a common bedplate with the motor. There are two of these sets, both carried on the main turbine bedplate. Only one works at a time, but it is automatically superseded by the other in the event of a failure of fuel or lubricant supply. The fuel pump has a capacity of 75 gal. a min. at 650 lb. per sq. in. The lubricant pump is of the Imo type and delivers 70 gal, per min. at 50 lb. per sq. in.

Auxiliary fuel pump set. — The auxiliary fuel pump is driven at 1 400 r.p.m. by a battery-fed 1/4 HP motor, the combined set being mounted adjacent to the main turbine bedplate. Its function is to supply fuel from the fuel tank on the locomotive underframe to the suction side of the main fuel pump. It is a gear type pump rated at 10 gal. a min. at 10 lb. per sq. in.

Auxiliary lubricant pump set. — The function of this set is to supply lubricant to the turbine and gear bearings during the cooling period, and is similar in capacity and design to the auxiliary fuel pump.

Lubricant coolers. — The heat from the lubricant is dissipated in the cooling equipment comprising two air blast radiators. They consist of cooling tubes of the wire wound Clayton-Still pattern extending between the top and bottom headers. The air ducts are of aluminium sheet and converge at the entry to an axial flow 32 1/2 in. fan mounted in the roof and driven by a 10 HP series motor at 1 480 r.p.m. fed from

View of one of the driving cabs, both of which are identical.

the auxiliary generator and drawing approximately 16 000 cu. ft. per min. of air through the cooling elements. Heat dissipation capacity is 120 kW with 70° F ambient and 180° F lubricant entry temperature.

Air compressor. — This set supplies air at 100 lb. per sq. in. for operating the brakes, electro-pneumatic control apparatus, windscreen wipers, and so on. The compressor is air cooled and has a piston displacement of 38 cu. ft. per min. at 243 crankshaft r.p.m.; it is driven by a 8 HP motor. The motor is auxiliary generator fed. An automatic governor switches the motor on and off to maintain pressure in the main reservoir between 85 and 100 lb. per sq. in.

Vacuum exhauster. — Two reciprocating four-cylinder exhausters provide the brake power for the train. Each is direct driven by a flange mounted motor at 750 r.p.m. for normal maintaining and application, and at 1 200 r.p.m. for release; both are stopped in an emergency application. The two machines are capable of creating 25 in. of vacuum in a train of 80 cu. ft. train pipe and cylinder capacity in 45 sec. The swept volume of each is 85 cu. ft. per min. at 7500 r.p.m.; the power input is 4 HP. The motors are battery fed so that the brakes will not be applied by the shutting down of the turbine in stations or when coasting.

Traction motor blowers. — The three traction motors on each bogie are force ventilated by a centrifugal blower direct coupled to a 11.25 HP auxiliary generator fed motor. The air is distributed by means of sheet aluminium ducts and leather bellows to the motor air inlet flanges at a rate of 8 000 cu. ft. per min. at 6-in. water gauge total head at 1 460 r.p.m.

Train heating boiler. — For the train heating requirements a vertical fire tube oil-fired boiler of 1 500 lb. per hr. steam capacity is installed at 80 lb. pressure per sq. in. The operation is semi-automatic and a special feature is the provision of a high-pressure combustion air blower and flow retarders to ensure flame stability during air pressure fluctuations due to high train speed and tunnels.

Air filters. — The 40 000 cu. ft. per min. of air required for the gas turbine at full load is drawn through filters installed in the turbine compartment. Of the dry fabric type, they can be cleaned by reverse blowing in position by compressed air nozzles provided in the turbine compartment, a feature which, it is considered, will materially reduce the rate of fouling of the blades.

Operation and control.

All operations for the stopping, starting, and control of the locomotive are remote controlled from either cab; the equipment installed in each cab is identical. All controller handles, push buttons, and indicating instruments are grouped conveniently on the driver's desk. The procedure for starting the locomotive is extremely simple. The driver requires only to operate the switch key and to press the turbine start button, and on a green light appearing one minute later indicating that the turbine is running at idling speed, switch on the brake compressor and exhauster. The locomotive is ready for service after a 5 min. warming up period when starting from cold.

To move the locomotive with or without load the brakes are released, the reversing lever of the master controller moved in the correct direction, and the power lever set to the position required. This lever has no notched position, but can be set and left in any position between no power and full power. For simplicity, this same lever determines the starting tractive effort developed between that required for locomotive manœuvring and a maximum determined by wheel slip consideration. The driver needs not notch up this lever as the train speed rises. The sequence and timings of the various events in the process of starting the turbine are determined by a drum-type sequence controller driven by an electric motor.

The driving technique required has been simplified by an elaborate system of control and has been designed to provide means for the driver to control the speed of the train by regulating the tractive effort developed at the wheels. In general, the control equipment function is to relate to each quantity to be regulated a proportionate voltage, and to cause that voltage to control relays, and to provide electric servo means for adjusting the quantity to the required value. As a example, if traction conditions change so as to demand a higher tractive effort, such as a rising grade, the increase of current to the traction motors from the main generators causes the turbine speed to drop.

This is immediately reflected in a reduction of voltage from a tachometer generator driven by the turbine. This, through the medium of a voltage relay, weakens the excitation of the generators to reduce their output voltage in the ratio of increased current demand, thus maintaining the turbine output at the value selected by the power lever of the master controller. The equipment used in the main power circuits is the same as for an electric locomotive. Each traction motor is controlled and protected by an electro-pneumatic unit switch, and its field is reversed by an electro-pneumatic drum switch.

The auxiliary circuits are also controlled by conventional electric traction apparatus. In the subsidiary control and regulating circuits special devices have been designed whose function is to apply to servo devices in the control circuits, voltages proportional to the response required by the position in which the driver has placed the controller lever. These servo devices are of the vibrating contact type and they control field strengths and servo motors to produce the desired result.

The combined fuel and boiler water tank is located under the underframe between the bogies. A transverse division plate separates the 995 gal. fuel section from the 660 gal. water section. Both sections can be made available for fuel if required by removing a cover from an aperture in the division plate; remote tank reading is provided. With the exception of these tanks all the equipment is housed inside the body of the locomotive.

The following sub-contractors supplied materials for the locomotive :

Brake equipment, air compressor and vacuum exhausters	Westinghouse Brake and Signal Co. Limited.
Machining and assembly of bogies and bogie components	Yorkshire Engine Co. Limited.
Train heating boiler	Spanner Boilers Limited (Laidlaw-Drew-Spanner burner).
Wheels and axles	Taylor Bros. and Co. Limited.
Axleboxes	Hoffmann Manufacturing Co. Limited.
Springs	Jonas Woodhead and Sons Limited.
Buffers	Geo Turton, Platts and Co. Limited.
Hydraulic dampers	Girling Limited.
Swing link resilient units	Metalastik Limited.
Draw-buff and other resilient units	Silentbloc Limited.
Aluminium alloy	James Booth and Co. Limited.
Pneumatic warning horn (Desilux)	C. V. Desiderio Limited.
Battery	Chloride Batteries Limited.
Air filters	Vokes Limited
Blowers for traction motors	Keith Blackman and Co. Limited.
Cooler fan for lubricating oil	Davidson and Co. Limited.
Main fuel pumps	Dowty Equipment Limited.
Main lubricating pumps (I. M. O.)	Mirrlees (Engineers) Limited.
Auxiliary fuel and lubricant pump	Varley Pumps and Engineering Limited.
Circular windows glazed with Beclatite rubber	Beckett, Laycock and Watkinson Limited.

NEW BOOKS AND PUBLICATIONS.

[**385** (02]

Directory of Railway Officials & Year Book, 1952-1953. — London : Tothill Press Limited, 33 Tothill Street, Westminster, S. W. 1. — One volume of 558 pages (8 1/2 × 5 1/2 in.). (Price : 40 s, net.)

The *Directory of Railway Officials and Year Book 1952-1953* reaches with the present volume its 58th year of publication.

The first edition was issued in 1895 and at that time comprised 270 pages of text including an index to countries, an index to names of railways and the comprehensive personal index of railway officials, which is still a valuable feature of the volume.

The present edition should prove as valuable as its predecessors, and there has been no markedly change in the presentation of this volume with the current edition. All entries are still divided into one or two main divisions, namely, British Commonwealth (regardless of Dominion or Colonial status) and Foreign. Each of these sections is again sub-divided geographically into continents and countries.

The most important change in administration of a national railway system is that which has taken place in India, where the railways are now constituting six zones. Details of all the new systems have been included. To enable the changeover to be more easily comprehended, entries for the former and the new railways are cross-referenced.

In the Asian section, Nepal has been added, where two systems are in operation.

The information given for the railways of Western Germany has been revised.

It has still been impossible to obtain complete and reliable information from most of the « iron curtain » countries of Eastern Europe.

Under the heading of international associations, particulars of the Pan American Railway Congress Association are now included.

This annual will be, as in the past, of the greatest interest to all those interested in railway circles.

A. U.

[**625** .28]

Dr. Eng. FLÖSSEL (Wolfgang). Baurat am Badischen Staatstechnikum, Karlsruhe. — **Bergsteigefähigkeit und Literleistung**. *(Climbing capacity and power per litre)*. — One volume of 284 pages (7 × 9 in.) with 157 figures and 25 tables. — 1950, Stuttgart, Frankh'sche Verlagshandlung, Kosmos-Verlag, Pfizerstrasse, 5-7.

We are constantly coming across the fact that two motor vehicles having the same maximum speed have a very different climbing capacity. This idea serves as the starting point of the thesis developed in this work.

The author examines a series of definitions suggested for the elasticity of a motor and then himself gives a definition which can be expressed by a coefficient. The latter is the product of two others, one representing the elasticity of the motor couple and the other the elasticity of the speed of rotation. A very clear distinction is

made between the elasticity of the motor and that of the vehicle.

These conceptions are supported by a great many results of trials and also by comparisons with foreign types of motors.

The determination of the coefficients defined in this way for various types of motors leads to a study of the various circumstances which accompany and influence their working. This includes thermodynamic developments, which show the influence of the number of revolutions.

Road vehicles only are considered in the first part of the book. Railway traction is considered in a second part entitled : « The elasticity of rail motor vehicles ». The author studies in this part the functioning of the steam locomotive, the electric locomotive, combustion engines and various systems of transmission used.

In the opinion of authorised commentators, the work may be of value in assisting builders to determine the arrangement and proportions of engines according to the service for which they are to be used. It is likely to interest those who have to study the operating or administration of road or rail vehicles.

E. M.

[**654**]

Fortschritte der Funktechnik und ihrer Grenzgebiete (*Progress in radio technique and allied fields*), 7th and 8th volume published under the direction of Eng. H. RICHTER. — One volume of 386 pages (7 × 9 7/8 in.) illustrated. — 1950, Stuttgart, Frankh'sche Verlagshandlung, Kosmos-Verlag, Pfizerstrasse, 5-7.

The publication « Fortschritte der Funktechnik und ihrer Grenzgebiete » is the natural complement to the manual « Handbuch der Funktechnik » well known for the last fifteen years in German centres specialising in radio questions.

This first post war volume contains information on the ten years, 1940 to 1949, a very remarkable period in the history of radio technique.

The work consists of seventeen chapters by various qualified authors. Intended to promote the German radio industry, it has undoubted scientific value, besides its technical and practical character.

It deals first and foremost with wireless receiving sets; their construction, measuring methods, the finding out of faults, the technique of switching over. These questions are gone into from both the technical and commercial points of view. Important progress is also reported in electroacoustics, television, oscillographs, magnetophones, frequency modulations. A few American innovations are described in detail.

The presentation of the receiving equipment put on the export market in 1941-1942 is accompanied by some 50 diagrams of the connections.

The work also deals with special questions relating to high frequency technique, the importance of which is well known in the utilisation of electric waves.

E. M.

[**656** .212 .5 (43)]

Rangiertechnik. *(Marshalling yard technique)*. Special number of the *Eisenbahn Technische Rundschau (E.T.R.)*, March 1952. — Drafted by the Special Commission for the marshalling yard technique of the Deutsche Bundesbahn. — One brochure (8 × 15 3/4 in.) of 58 pages, illustrated. — 1952, Cologne, Darmstadt, Carl Röhrig-Verlagshandlung (Price : D.M. 8).

There is no need to insist upon the importance of marshalling yards in the working of railways. The rapid and economic flow of the traffic depends on their geographical position and functioning. On the other hand the design and equipment of such costly installations must be directed towards obtaining a satisfactory output.

The question has been included several times on the agenda of the Sessions organised by our Association. In the reports and discussions besides other inventions, we come across the studies and works of Ernst FRÖLICH (the inventor of the brake which bears his name), who is considered to be in Germany the first and foremost pioneer of the development of marshalling yard technique.

In 1927, the Central Administration of the Reichsbahn created the « Society for studying the technique of marshalling » to which it owes the perfecting of the installations for marshalling the trains in the large yards. Recently, in 1950, a « Special Commission on Marshalling Technique » was set up for the advancement of scientific work in this field.

Like the old Society, this special Commission decided to publish annual reports in order to make known to specialists and interested members of the public the results obtained and the present situation of this special branch of railway technique. This first report which is included in Special Issue No. 12 of the *Eisenbahntechnische Rundschau* is one of the series of such articles that the Study Society published in the *Verkehrstechnische Woche*. After a few introductory notes, this preliminary publication gives the annual report on the activities of the Commission during the year 1950/51. It includes a list of the special problems which were examined and the solutions suggested for some of them.

A note by the Chairman of the Commission gives the history of the technique of marshalling since the beginning of the railway, points out the problems of the future and gives a review of the position in German yards with a daily capacity of at least 1 000 wagons.

The issue also contains notes on :

Ernst FRÖLICH, a pioneer of marshalling technique;

the state of the Technique of marshalling in Germany and other countries;

the operating methods and the cost of operating marshalling yards;

the butt brakes.

The work ends with a fairly comprehensive bibliography covering the periods between 1926 and 1951. The works in question are mainly German, but there are also a few French and English studies relating to installations outside Germany.

E. M.

[385 .113 (460)]

RED NACIONAL DE LOS FERROCARRILES ESPANOLES. — **Proyecto de Memoria del Consejo de Administración. Ejercicio de 1950.** *(Spanish National Railways. Project of Report of the Administrative Council. Year 1950).* — One volume (8 1/4 × 12 in.) of 210 pages with maps.

At the end of 1950, the Spanish National Railways extended to 12 948 km (8 077 miles). Single track lines, which form the majority of the lines, account for 11 853 km (7 365 miles) of this total.

The operating results for the year 1950 in question are given by the following figures in millions of pesetas :

Receipts	4 008
Expenses	4 350
Deficit	342

The operating coefficient was 108.52 %, an improvement compared with the previous year when it was 128.14 %.

The very complete information on the various aspects of the activities of the railway are grouped together in five chapters, entitled as follows :

Chapter I. First costs, installations and equipment.

Chapter II. Railway operation.

Chapter III. The social activities of the R. E. N. F. E. on behalf of its staff.

Chapter IV. The economic and financial results.

Chapter V. The reconstruction and improvement of the railway.

Chapter VI. Supplementary services.

Chapter VII. Charges.

A preliminary note gives some general remarks on the characteristics of the year and stresses the most remarkable facts, which are gone into in detail in the report itself.

As a whole, the traffic was greater in 1950 than in the previous year. The increase is due to the goods traffic, especially the slow goods traffic, as there was a slight falling off in the number of passengers. There was also an increase in the train kilometres for both goods and passenger traffics.

A fairly substantial increase in the rates was authorised as from the 5th April. This was justified by the increased salaries paid to the staff and the increased cost of various products and materials used. However, in view of the date these increases were introduced, the three first months of the year account very largely for the operating deficit which, as seen above, was less than that of the previous year.

The report bears witness to the continued efforts made to improve the system, both as regards operation and equipment. Chapter II gives a great many statistics showing the favourable evolution of the transport economy. In Chapters I and V, the authors have noted the progress realised during the year in restoring and modernizing the track, the signalling, buildings, stations, telecommunications and the rolling stock.

Chapter IV gives a very detailed analysis of the economic results and a very complete table showing the financial situation.

Chapter III, which is relatively short, gives a synthesis of the social activities of the R. E. N. F. E. The institutions and organisations on behalf of the staff include instruction, education, professional training, material and moral wellfare, health and pensions.

Among the supplementary services, there are first of all the forestry services which supply the sleepers and timber required for wagon repairs. Chapter VI then deals with the legal system of road transport and the part played by the R. E. N. F. E. in operating such services.

The burdens which fall upon the undertaking are the taxes on transport and syndicate and social charges. The figures relating to the five years that have passed make it possible to judge of their extent.

This document, prepared according to a rational plan and including all the relative statistics, gives us in facts and figures a picture of the working of the undertaking. It also shows us how the railway operated by the R. E. N. F. E. has profited in the last few years by the latest technical progress and modern methods of organisation.

E. M.

Competition for new designs of track brakes organized by the German Ministry of Transport.

We think our readers will be interested to learn that the Ministry of Transport of the German Federal Republic has decided to organize a competition for new designs of *track brakes.*

The organization of this competition has been entrusted to the Darmstadt Review « Eisenbahntechnische Rundschau ».

The object of this competition is to evolve new types of track brakes satisfactory from the technical and economic points of view, of light and average types, and if necessary of heavy types. As a brake of this latter type already exists, particular interest will be shown in light and average brakes.

The competition is open to any individual or firm whether German or otherwise, and competitors may send in one or more designs for the types of track brakes mentioned above.

The total prize money of 45 000 D. M. will be allocated as follows : First prize : 25 000 D. M.; Second prize : 12 000 D. M.; and Third prize : 8 000 D. M. The judges of the contest may decide to share the prizes amongst several competitors or to give one competitor more than one prize.

Designs must be submitted before the 16th February 1953.

The general and technical conditions covering this competition may be obtained from the Editor of the Eisenbahntechnische Rundschau, 8, Stephanstrasse, DARMSTADT, on payment of an entrance fee of 10 D. M.

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